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Project No. E-24-622 DATE 8/23/82

Project Director: Alan L. Porter School/~~Lab~~ ISyE

Sponsor: National Science Foundation

Type Agreement: Grant No. OIR-8209893

Award Period: From 7/15/82 To 12/31/83 (Performance) 3/31/84 (Reports)

Sponsor Amount: $46,286 Contracted through:

Cost Sharing: $883 (E-24-356) GTRI/~~GIT~~

Title: Review of the Processes of Interdisciplinary Research

ADMINISTRATIVE DATA

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Project No. E-24-622

School/~~Lab~~ ISyE & OIP

Includes Subproject No.(s) B-10-615 and G-43-602

Project Director(s) Dr. Alan L. Porter — GTRI / ~~GIT~~

Sponsor National Science Foundation

Title Review of the Processes of Interdisciplinary Research

Effective Completion Date: 12/31/83 (Performance) 3/31/84 (Reports)

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FINAL REPORT
Volume 1

INTERDISCIPLINARY RESEARCH (PROBLEM-FOCUSSED, MULTI-SKILLED RESEARCH) – NATIONAL SCIENCE FOUNDATION EXPERIENCES

By

Alan L. Porter
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Prepared for

NATIONAL SCIENCE FOUNDATION

March 1984

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF INDUSTRIAL & SYSTEMS ENGINEERING
ATLANTA, GEORGIA 30332

1984

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

FINAL PROJECT REPORT
NSF FORM 98A

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PART I–PROJECT IDENTIFICATION INFORMATION

1. Institution and Address	2. NSF Program	3. NSF Award Number
Georgia Tech Research Institute Georgia Institute of Technology Atlanta GA 30332	Office of Interdisciplinary Research	OIR-8209893
	4. Award Period From Jul 15,82 To Dec 31,83	5. Cumulative Award Amount $46,286

6. Project Title

Review of the Processes of Interdisciplinary Research

PART II–SUMMARY OF COMPLETED PROJECT *(FOR PUBLIC USE)*

Interdisciplinary research processes can be described by the mix of research skills involved using the new 'STRAP' framework. Such characterization by areas of substantive expertise and techniques, along with organizational factors, yields insights for the conduct of problem-focussed research.

The first part of this project was a critical review of the literature on interdisciplinary research, summarized in a bibliographic essay and annotated bibliography. The second part involved reconceptualization of interdisciplinary processes in terms of multiple skill combinations. This new conceptual framework is tested in the third part of the study. Forty problem-focussed projects supported by five NSF programs were studied by using the proposals, obtaining peer review information, conducting phone interviews with the researchers, and considering some project outputs. Results indicate that interdisciplinary research is accepted by certain 'open' academic disciplines. Stable sponsor support is more likely in basic research areas than in applied or policy research. Peer reviewers tend to rate interdisciplinary projects less positively, and reviewers favor academic principal investigators, especially those associated with the reviewers' own disciplines. We recommend ways to develop more effective support mechanisms for interdisciplinary research.

PART III–TECHNICAL INFORMATION *(FOR PROGRAM MANAGEMENT USES)*

1. ITEM *(Check appropriate blocks)*	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM	
				Check (√)	Approx. Date
a. Abstracts of Theses	X				
b. Publication Citations		X			
c. Data on Scientific Collaborators		X			
d. Information on Inventions	X				
e. Technical Description of Project and Results		X			
f. Other *(specify)*					

2. Principal Investigator/Project Director Name *(Typed)*	3. Principal Investigator/Project Director Signature	4. Date
Alan L. Porter		3-23-84

INTERDISCIPLINARY RESEARCH (PROBLEM-FOCUSSED, MULTI-SKILLED RESEARCH) — NATIONAL SCIENCE FOUNDATION EXPERIENCES

Final Report to the National Science Foundation

Georgia Institute of Technology
March, 1984

by

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We gratefully acknowledge the support of the National Science Foundation, Office of Interdisciplinary Research, under Grant OIR-8209893. The views expressed are those of the authors and do not necessarily reflect those of NSF or the Georgia Institute of Technology. We thank Terry Connolly, our co-principal investigator who left his insights and guidance as he moved to the University of Arizona, and Elisabeth Kotzakidou, who served as graduate research assistant. We deeply thank the NSF Program Managers who helped us access projects and shared their knowledgable perspectives:

--James C. Aller, Science and Technology to Aid the Handicapped Program
--William A. Anderson, Earthquake Hazard Mitigation, Societal Response Research
--James H. Brown, Division of Behavioral and Neural Sciences
--Steven E. Kornguth, Neurobiology Program
--John A. Maccini, Environmental Geosciences Program
--Charles L. Redman, Anthropology (Archeology) Program
--Joseph L. Young, Memory and Cognitive Processes Program.

We are especially indebted to the 40 busy researchers who took time to review our characterization of their projects and to discuss that research with us.

For further information, contact Alan Porter by phone: (404) 894-2330, or mail: ISyE, Georgia Tech, Atlanta, GA 30332.

EXECUTIVE BRIEF

INTERDISCIPLINARY RESEARCH

Interdisciplinary Research (IDR) presents unique and substantial difficulties for researchers and research managers. Yet it is widely practiced because it often constitutes the most important scientific and engineering research, both in its potential for intellectual breakthroughs and for the solution of critical societal problems. IDR is often performed within organizational structures that are not oriented toward it. There are substantial incentives to understand how IDR works, from concept generation and review through the reseach process to the resulting products and their use, in order to improve its performance.

STUDY OBJECTIVES

The Office of Interdisciplinary Research of the National Science Foundation (NSF) is committed to understanding and facilitating IDR. It commissioned this study to:

(1) Identify the most important literature on IDR;
(2) Critically synthesize knowledge on IDR to guide research on IDR processes;
(3) Examine a number of projects supported by various NSF programs to gain additional insight into the factors that help and hinder IDR.

STUDY COMPONENTS

The study contains threee components: bibliographic, conceptual, and empirical.

The literature review built on our experience in studying IDR and the process of preparing a book of readings. A computerized search and informal networking extended it so that Volume II of this report consists of a bibliographic overview and a selection of annotated items current through November, 1983.

As our literature synthesis and preliminary empirical work progressed, we became convinced that the usual approach to IDR as an interaction among scholarly disciplines was inadequate. As a consequence, we rethought the bases of our understanding of IDR. The result was the STRAP framework for describing the static properties of an IDR project. The key change is that "intellectual skill" replaces discipline as the primary intellectual unit of analysis. Organizational and personnel factors are also included. Hypotheses developed from this framework guided our empirical work.

The empirical work itself involved the study of 40 research projects from five NSF programs, involving basic, applied, and policy research. These five are Archeology, Neurobiology, Environmental Geosciences, Science and Technology to Aid the Handicapped, and Earthquake Hazard Mitigation-Societal Response. The sample was purposive, emphasizing IDR projects within accomodating programs. We interviewed the NSF program managers about IDR funding, project management, and evaluation. We then obtained the proposals and sanitized versions of the peer reviews. We abstracted information from each proposal, then mailed this to the principal investigator. Phone conversations clarified and augmented our interpretations. Volume I of this report consists of the analysis of the research process and peer review data in relation to the previously framed hypotheses.

CONCEPTUAL HIGHLIGHTS

Our project deals with IDR at the program and project levels. Research program development, whether within NSF or another formal research organization, or in an informal network of researchers, involves both intellectual and organizational factors. The intellectual factors are usually lumped under the category of disciplines. These factors interact with organizational factors, for example in the areas of research training and project management.

Discipline, which carries both intellectual and organizational connotations, especially in academe, has serious limitations as a primary unit of analysis for studying research processes. The problem is most obvious at the project level where successful IDR is most commonly viewed as the integration of various disciplinary components to form a single analysis. These limitations include the following:

* Intellectual and/or organizational differences may be more acute within a discipline than between disciplines. For example, humanistic and behavioral (clinical) psychologists are further apart than some experimental chemists and physicists;
* Some individual researchers do not fit neatly within a single disciplinary category;
* Research areas involving intellectual communities do not always map cleanly onto disciplines;
* IDR problems may be addressed by individuals as well as teams;
* The central role of discipline tends to narrow the focus on IDR to academic research, an ill-founded restriction.

The STRAP framework, which we developed during this project, offers a new perspective on IDR. Its driving premise is that there is a class of problems whose solution requires many intellectual skills. These skills may or may not relate closely to disciplines and may or may not be combined within a single individual. Skills are divided into substantive area expertise (S) and technique expertise (T). These skills may be exercised at either the expert or journeyman level.

The remaining STRAP variables are:

(1) Range (R)-the degree to which the substantive areas and techniques reside within established research areas;
(2) Administrative Unit Complexity (A)-the number and relationship of the organizational units involved in the conduct of the research;
(3) Personnel (P)-the number and relationship of the researchers involved in the project.

STRAP broadens the consideration of problem-focussed research to encompass non-academic organization and individually performed IDR. It suggests new strategies for training researchers and alternative ways of composing research teams.

EMPIRICAL RESULTS

Characteristics of the Projects Studied

These projects are viewed by 87% of their principal investigators (PIs) as interdisciplinary. Indeed this characterization is appropriate with an average of 6 intellectual skills identified per project and 60% of the projects involving skills from more than a single research area.

In the areas we studied, academic departments proved surprisingly open to drawing on research skills beyond traditional disciplinary domains to attack interesting problems. Researchers had high expectations of professional reward for IDR. However, such open departments seem to constitute only a fraction of academic units.

Findings Relating to the STRAP Framework

The PIs understood the concept of intellectual skills that were not simple images of disciplines. About 3 substantive areas and 3 techniques characterized the median project.

In the projects we studied it was typical for each researcher to possess a relatively small number of skills. Laboratory based projects had a greater skill overlap than did other projects.

Projects involving many substantive areas are more likely to be team research than those involving a comparable number of techniques. Individuals more readily master techniques than substantive areas.

As indicated in Table ES-1, applied, as contrasted with basic, research projects show a wider range of substantive areas and techniques, more participants from outside the PI's discipline, less likelihood of continuing sponsor support, and greater likelihood of ad hoc project team arrangements.

Policy research projects vary considerably among themselves, tending to be intermediate between basic and applied projects in skill mix and team permanence, but lowest in likelihood of continuing support.

Applied research projects have less skill overlap among participants than do basic or policy research projects.

Organizational barriers to the conduct of research were noted in only 5% of the projects.

Peer Review

Peer ratings tend to be more favorable for academic PIs (1.63) than for non-academic PIs (2.18; $t=4.29$, $p < .0001$).

Peer ratings tend to be more favorable for proposals funded in basic research (1.51) than for those in applied and policy research (2.05; $t=4.55$, $p < .001$). The applied and policy projects are all in the Engineering Directorate of NSF.

Peer ratings tend to be less favorable for more interdisciplinary projects (rho=.23).

Peer reviewers from disciplines differing from the PI rate proposals less favorably (2.07) than do reviewers closely associated with the PI's discipline (1.73; $F=6.70$, $p=.01$).

IDR Project Differences Across NSF Programs

As Table ES-2 indicates, the interdisciplinary characteristics of the projects differ across the five NSF programs, for instance:

* Archeology projects tend to involve the largest teams.
* Geoscience and Science and Technology to Aid the Handicapped (STAH) projects tend to ad hoc research teams; Neuroscience and Archeology projects lean toward more permanent teams.
* Professional reward for researchers is more questionable on applied and policy research projects.
* STAH projects involve the greatest percentage of participants from disciplines different from the PI.
* STAH and Archeology projects are the most interdisciplinary.

IDR in Academe

Some academic departments are "open" to IDR while others are "closed" to it. This counters the stereotype of disciplinary academic departments opposing IDR.

Cross-disciplinary training arrangements, as exemplified by British interdisciplinary and U.S. Neuroscience Ph.D. programs, offer potential for training researchers to practice IDR.

RECOMMENDATIONS

NSF has made progress in furthering appropriate interdisciplinary research. Further development is possible through selected activities in three areas:

(1) Carefully chosen research on IDR processes;
(2) Prods to academe;
(3) Changes in NSF practices.

We urge research on two facets of IDR. The STRAP framework offers real promise in broadening 'IDR' perspectives to problem-focussed research demanding of multiple skills. In particular, improved measures of intellectual skills, critical review of the other variables, and empirical testing of the link between research processes and products are needed. In addition, an empirical study of organizations "open" and "closed" to multiple-skilled research and their characteristics would help clarify the organizational role in facilitating/discouraging IDR. A detailed analysis of the differences between "open" and "closed" academic departments could be truly enlightening.

NSF and others can act to minimize organizational resistance to IDR from academe. Budgetary arrangements for sharing overhead among various participating academic units can be encouraged to reduce financial tensions. Professional career reviews of academics could incorporate reviewers from their areas of expertise, whether or not these lie inside the traditional boundaries of their academic discipline. Postdoctoral grants and appointments might require the transfer of new intellectual skills into the group where the postdoc will be working. Major equipment grants or purchases could require shared use, preferably by researchers from different units.

On the NSF front, the Foundation should take into consideration the extra work involved in encouraging, reviewing, and funding IDR proposals by its program managers. It should encourage mechanisms for multiple program funding of IDR projects, more than is presently done. NSF should consider an "IDR set aside" so that good research does not drop through the cracks between existing programs. Small businesses have largely untapped potential as performers of IDR. NSF should move to facilitate their participation in its programs.

As documented in this study, the peer review process of NSF presents special hurdles to IDR. Review by a disjoint set of experts in individual areas would seem to doom an IDR proposal to lower ratings than an equivalent disciplinary project, based on our observation of less favorable ratings by reviewers from different disciplines than the PI. Multiple panels only mean multiple jeopardy. NSF should instead seek reviewers who possess sufficient breadth and are committed to the proposed research area. Alternatively, it should adjust award mechanisms with the expectation of weaker ratings for IDR projects. Incorporating feedback into the review process [e.g. a delphi-like process in which reviewer comments are fed back to the PI and then all comments are circulated iteratively before final ratings are made) could limit the problems of reviewing IDR projects.

NSF was repeatedly credited with facilitating the development of IDR. Strengthening the mechanisms for proposal review and project oversight of IDR within the Foundation should serve to further lower the barriers to and reap the high payoffs from IDR.

TABLE OF CONTENTS

1. INTRODUCTION

This study addresses interdisciplinary research (IDR) projects sponsored by various National Science Foundation programs. The aims are (1) to learn how IDR can be used and promoted to enhance the effectiveness of NSF programs and (2) to learn how the individual IDR project can be conducted effectively. Thus the project deals with both the strategic and tactical levels of research management.

This project should interest research managers and practitioners, as well as scholars of IDR processes, because it is, in our opinion, the first systematic, data-based study that involves IDR projects in basic research areas. NSF is primarily oriented to supporting academic basic research. This area has not typically been viewed as involved in IDR. In our past work we concentrated on projects and programs, such as the NSF Technology Assessment Program (Rossini et al., 1981), that emphasized problem-solving and, thus, could be classified as applied or policy research. However, an exploratory study on the dynamic development of the discipline of anatomy (Rossini et al., 1984) convinced us that, at least in the biomedical area, basic research could indeed be interdisciplinary in nature.

We studied projects, 40 in number, from five NSF programs: Environmental Geosciences, Neurobiology, Archeology, Earthquake Hazard Mitigation: Societal Response Program, and Science and Technology to Aid the Handicapped. Of these, the first three reflect basic research programs; the other two are more applied or policy-related. Thus the study involves a wide range of both programs and projects. Our information came primarily from discussions with program managers, perusal of proposals and certain peer review information, and phone interviews with project principal investigators.

A major difference between this project and others conducted to study IDR is that we go rethink "discipline" as the essential unit of analysis. In its place, we examine "intellectual skills," using a descriptive framework--'STRAP'--that captures what we believe are the principal static dimensions of IDR projects.

The report next presents this conceptual framework for dealing with IDR. The third section discusses the methods used in this project to gather and analyze data. Then general project hypotheses and data are presented and analyzed, followed by a section devoted to exploration of STRAP framework project hypotheses. The sixth section addresses peer review and other program level concerns. The final section offers conclusions and new directions.

2. CONCEPTUAL FRAMEWORK

In order to study interdisciplinary research (IDR) it is necessary to establish a frame of reference within which to deal with it. Such a frame of reference should consider at least two levels of aggregation, the program level and the project level. The program level deals with the conscious attempt to establish a research program within a particular area, such as within an industrial organization or by the National Science Foundation, or the unselfconscious group dynamics of researchers trying to develop an intellectual area of interest. At this level one is involved with institutional mechanisms to promote IDR as a means of program development. Such approaches attempt to create an environment where successful IDR is possible. By contrast the project level involves the static and dynamic factors operative in the conduct of IDR projects. Success in IDR is judged by the criteria of validity and utility, operative in all forms of research, and integration of the various components of IDR, proper to IDR alone. Integration can be judged by an evaluation of output (Rossini et al., 1981), an evaluation of process (Birnbaum, 1979), or a combination of both.

First, we consider the <u>program</u> level where a number of factors can affect IDR. Organizational factors include goals, policies, and strategies. For IDR to succeed, these must be favorable toward it. The principal offender here is usually thought to be the university because of its nominally disciplinary organizational structure. However, a number of major research universities have begun to improve the climate for IDR through the establishment of area or problem oriented research units (Teich, 1979; Friedman and Friedman, 1983) and flexible internal budgeting arrangements that allow for overhead sharing among units. Equally difficult for IDR, but not as widely recognized as such, are large R&D organizations with strict departmental lines and rigid procedures for charging time (Rossini et al., 1978; 1981). It must be possible to organize teams for IDR, where needed, with a minimum of difficulty, even when these teams are made up of individuals from different units within the organization, or even from different organizations.

Rewards for successful performance of IDR should be the same as those for any successful performance of research. Academe is the principal problem area as the process of peer review seems to put a premium on disciplinary research. The peer review process of NSF is vulnerable to the same problems. Because of its academic orientation, NSF may have problems adequately reviewing crossdisciplinary concepts, proposals, and results using reviewers enmeshed in traditional academic disciplines.

Selection and training of individual researchers is the final organizational factor. A very useful researcher profile for IDR is Walter Hahn's "T Person" (personal communication). The T Person has a deep intellectual root--the stem of the T--and a broad intellectual range at lesser depth--the cross of the T. Unfortunately the usual graduate research training does not develop the T Person. Thus within the research organization, encouragement and opportunity for further development of individual researchers through enhancing their acquaintance with other intellectual areas would seem sound program strategy. Where teamwork is required, additional development in communication and management skills, again not a common part of formal research training, appears a reasonable step. In addition to these factors, there are strategic approaches to sharing equipment and facilities and to the physical location of research groups that may prove useful in developing IDR at the program level (S. Kornguth, private communication, 1983).

The _project_ level, to which we now turn, is more commonly dealt with than the program level (see Rossini et al., 1978;1981; Birnbaum, 1979). The specific interactions between researchers trained in different disciplines take place within the context of a research project. The description of a project should encompass static, including the structural features and boundary conditions, and dynamic considerations, incorporating the processes and interactions of a research project.

The usual approach to IDR is to treat the IDR project as an interaction among individuals trained in different disciplines and between the disciplines themselves. We have found that "discipline" makes a poor unit of analysis through which to discuss the intellectual and organizational complexity of an IDR project. An alternative, arising from our analysis, is to substitute the relatively operationalizable notion of _intellectual skills_ for "discipline." (See Appendix A for an operational description of intellectual skills and the new 'Strap' framework.)

These intellectual skills consist of substantive areas of knowledge and techniques used for acquiring and manipulating knowledge. Every research project should incorporate at least one substantive area and one technique. Intellectual skills are not equivalent to disciplines, as an intellectual skill may be used within several disciplines and each discipline makes use of a number of intellectual skills. Each IDR project requires a number of intellectual skills. These skills may be the property of a single individual or a team of researchers--thus IDR may be individual as well as team. They may lie within the same closely defined research area, or they may cross grand categories of knowledge such as the social and life sciences. Such crossing is hypothesized to be more likely in applied and policy research than in basic research. The broader the range of intellectual skills required for the project, the more likely the project will be to involve collaboration. Yet major paradigmatic differences within the same team appear to be rare. Skills may be required at an expert or frontier level or may simply be needed as a tool, to be used without being refined. However, at least one skill in each research project should be at the frontier level.

Completing the STRAP framework for the static description of a project are two other variables, one dealing with the number and relationships of the organizational units supplying personnel for the project, the second with the number of personnel, and, if a team, the permanance of their relationship. It is hypothesized that permanent teams should be more effective than ad hoc teams. This characterization of a project's structure suggests the general hypothesis that the more complex the project, the more effective the organizational support and project leadership required for success.

A number of dynamic factors have been identified as important within the project (see Rossini et al., 1978;1981). These include consideration of leadership style with the desideratum that the leader both allow useful group process and shared decision making and, at the same time, be prepared to make any necessary "bottom line" decisions. Communication patterns within the project team are also important. These range from the "hub and spokes" pattern in which only the leader communicates with any other participants to the "all channel" pattern wherein everyone communicates with everyone else. Also of significance is the problem identification and bounding pattern in which the problem is scoped, results evaluated, work iterated, and/or directions of investigation altered until closure is effected. In addition to these process factors, there are the problems, in team projects, of individuals with various intellectual skills, diverse judgments of the value of intellectual frameworks, differing approaches to data gathering and processing, and uneven ability to relate to colleagues of differing backgrounds coming together to perform the project.

Within team projects there are a number of possible approaches to integrating the project (Rossini and Porter, 1979). One approach, particularly apt for projects with breadth but not much depth of analysis, such as much policy-related research, is common group learning (Kash, 1977; White, 1975). In this approach, team members are given an initial assignment according to their expertise. The completed assignments are circulated among the group and criticized by the members. Then the assignments are redone to reflect this critique, but this time by a different team member, a non-expert. This process is iterated until convergence is reached. This approach makes the project in its entirety the common intellectual property of the entire group.

Another approach is negotiation among experts in which each expert team member works on the component of the project involving his orher expertise. When each receives the work of the others and offers critiques, the work is redone by the experts incorporating the critiques of the other team members. Iteration continues to coherence and closure. In this approach expertise is preserved, but enriched by the insights of non-experts. This technique is appropriate for projects with a substantial depth of analysis.

A common model may be used to incorporate inputs from diverse sources (an example is Enzer, 1974). While at first sight models appear to be a substitute for human interaction, the development and testing of a model often involves substantial group interaction. One caveat is that most models readily accept quantitative input, but are relatively opaque to qualitative input.

A final approach that may work for small projects, but is generally ineffective on large and complex projects, is integration by leader. In its extreme form the leader interacts with each team member individually while the team members are isolated from one another. This approach puts a substantial burden on the leader.

This current project differs from our earlier work in that it incorporates basic research, applied research, and policy research projects and attempts to develop approaches for improving IDR and using it effectively both at the program and project levels. Sensitivity to these distinctions is important as basic research consists overwhelmingly of primary data and theory development, while policy research is usually largely secondary. Strategies at the program level are institutional and long term, while project improvement needs to be effected quickly and within the research process. Our hypotheses, data gathering, and analysis reflect a wider range of concerns and a greater degree of subtlety than has been the case in the past. Tables 1 and 2 present the hypotheses we will consider. Most are discussed and developed in this section. Subsequent sections will discuss the evidence we uncovered that bears on these hypotheses.

Table 1

Some General Hypotheses Regarding Interdisciplinary Research (IDR)

	Hypotheses	Conclusions
1.	Assistant Professors will be under-represented in IDR.	Refined
2.	Major paradigmatic differences within a team will be very rare.	Not Supported
3.	Various strategies to integrate component parts of the research will work; integration by project leader will be least effective.	--
4.	Panel ratings will tend to be lower for proposals which appear interdisciplinary in content.	Supported
	A. To the extent this is so, we would anticipate that the correlation between panel rating and integration will be low to negative.	--
5.	Research production will be higher where the performing unit is familiar with the type of research.	Not Supported
6.	Prior experience together facilitates research productivity.	Supported
7.	Peer reviewers from traditional academic departments will be least open to interdisciplinary proposals. (Certain disciplines may be more open than others.)	--
8.	Peer review reflected in proposal-review panels and article reviews will be less protective of turf in more secure areas, thus be more open to differently trained researchers.	--

Table 2

Some Hypotheses Pertaining to the STRAP Framework

	Hypotheses	Conclusions
1.	Always at least 1 technique (T) and substantive area can be identified.	Partially Supported
2.	At least 1 S or 1 T will demand high expertise unless they reflect a cross-"paradigm" synthesis.	Supported
3.	Complexity in terms of S&T can be measured; it will not correlate simply with a tally of the number of disciplines represented on the core team.	Supported
4.	Problems requiring substantive expertise in two or more areas are more likely to need collaboration than problems requiring technique expertise in two or more areas.	Supported
5.	Rarely will basic research cross paradigms.	Supported
6.	Development work and policy research is far more likely to warrant crossing paradigms.	Supported
	a. Research support continuity is less (and crossing paradigms is a larger task) in these areas, hence collaboration is more suitable than single individual learning.	Partially Supported
	b. Permanent teams would have a great advantage over ad hoc assignments given the difficulties in welding effective teams of this nature, but this demands provision of research continuity.	Partially Supported
7.	Production (P) [and integration (I)] for ongoing research projects will be greater than for new ones (reflecting the start-up period necessary to achieve interdisciplinary teamwork).	Not Supported
8.	As project skill requirements increase in complexity, interpersonal and organizational dimensions become more important determinants of project success.	Not Supported
9.	Organizational constraints on collaboration may impede solution of complex research problems.	Not Supported
10.	Permanent or quasi-permanent research teams will be more productive than ad hoc teams.	Partially Supported
11.	It is easier to solve a development problem by partitioning it into discrete subproblems than to partition a problem in basic research.	Partially Supported

3. METHODS

This project consists of two parts--a bibliographic review and an empirical examination of 40 selected projects within 5 NSF programs. The selective bibliographic review was compiled in late 1982 and updated through November 1983. It appears as Volume II.

The project sought to obtain information on a range of interdisciplinary NSF programs. To this end, through the coordination of our project monitor, Richard Goulet, we contacted program managers to participate in this study (See Section 6). Alan Porter and Fred Rossini met with each to discuss interdisciplinary research management issues and to select interesting projects for analysis. We wanted to follow each project from inception (proposal), through peer review, into the research processes, and finally to see the outputs.

We sought a limited sample of projects that would be most informative as to interdisciplinary research processes. Neither we nor NSF program managers could accommodate a randomized, representative sampling. We lacked resources to investigate large numbers of projects less apt to be interdisciplinary in nature, and they had to consider what projects would be suitable for study. The resultant sample meets our main needs by providing a broad spectrum of studies with emphasis on interdisciplinary research. Some problem-oriented, disciplinary projects are included for comparison.

In addition to not being randomized, limitations of this sample of 40 projects with regard to the availability of research products must be noted. Some of the NSF programs included are quite young; others had sent their older project materials to the storage facility. As a result, many of the sample projects have not had a chance to complete their work. (Even had older projects been generally available, they would have come at the cost of faded memories about study processes about which we were most concerned.) In many instances, projects fit into an ongoing research stream, making it more difficult to ascribe products (e.g., journal articles) cleanly to a project. Due to these problems in measuring research output, our analyses of product quantity and degree of integration must be considered exploratory.

We obtained project information from the proposal, peer reviews, interaction with principal investigators (PI's), and review of research products. We were able to obtain copies of all 40 proposals to get research plans, skills required, team backgrounds, and so on.

Dr. Goulet acted as intermediary to provide us with sanitized review materials. These included reviewer discipline and type of institutional affiliation, rating, and selected observations pertaining to interdisciplinary aspects of the proposed research for 38 of the projects.

A single graduate student coded all the proposals to provide the basis for our dialogue with PI's. Pilot tests with 6 PI's indicated a need to recompile our information. The resulting form appears as Appendix B. The project sample was split, program by program, between Fred Rossini and Alan Porter. Each of us handled 20 projects. We filled in the form as best we could from the proposal information and mailed this to the respective PI for review and augmentation. Phone conversations with the PI (in all but one case in which two other key people were contacted as the PI was out of the country) served to correct our interpretations and extended to discussions of related issues.

We asked each PI to identify the products of the research in question. In some cases they provided copies; in others, we obtained copies at Georgia Tech. We did not systematically seek all products due to the limitations on product evaluation mentioned earlier.

Statistical analyses were performed on the resulting data coded by Porter and Rossini. Descriptive statistics were compiled for the full 40 project sample. Explorations of hypotheses made use of a split sample approach--wherever this made sense. This provided a check on the reliability of coding information by the two interviewers. More importantly, given the tentative nature of most of the hypotheses and the sample limitations, this provided an important check. The second set of 20 projects was held aside to replicate findings observed on the first 20.

Results of the statistical analyses are blended with qualitative observations in the following chapters. The next chapter addresses general characteristics of the projects studied. The following one explores the "STRAP" conceptualizations vis-a-vis those projects. That is followed by consideration of peer review and NSF programs.

4. PROJECTS

Interdisciplinary research (IDR) processes can be considered at four possible levels.

(1) Paradigms--An intellectual unit suggesting a community working within one over-arching intellectual framework. Paradigms may reside within a discipline, or cross disciplines.

(2) Programs--A critical research management unit. Programs may also be important to the cumulation of knowledge (e.g., that accrued in individual projects).

(3) Projects--The essential focus of research activity.

(4) Papers--And other specific research products provide the smallest particable unit for analysis of research.

Paradigm is not a major focus of this study. However, we do look for signals of intellectual differences within research teams. Program is considered in a later section. Projects within programs provide the sample for this study. This chapter addresses general descriptions and exploratory analyses of the 40 projects included. Papers and other research products are combined to form a weighted measure of research productivity (See Appendix C, V64). Because our sample of these research outputs is so uneven, we do not pursue analysis at the level of the individual paper here. (We have done so elsewhere; see Chubin et al., 1983).

"Project" at first glance seems a clean-cut unit of analysis. We can identify 40 discrete projects, but they are not always neatly delimited. From the NSF standpoint, projects are frequently funded in two or three segments of 12 months each. We considered this a single project when the expectation was for routine awarding of these succeeding segments. Often, however, such research represents part of a continuing effort. We tried to gauge this by coding the "stage" of the research (new or continuation). Research conducted as part of an on-going stream makes it very troublesome to allocate research products (e.g., papers) cleanly to individual projects. Besides temporal extensions of a line of research, one also finds parallel activities. For instance, Neuroscientists (and others) often have multiple sponsorships on contemporaneous projects in the lab that augment each other. Even sponsorship cannot always be neatly circumscribed. For instance, one archeological project involves scientists from two nations working in and with a third. Each of the three parties has different sources of support and even different missions. The Americans have NSF research support, but field support from a second source. Were one to attempt to measure, say, research output per NSF dollar, this sort of project would prove most challenging and frustrating.

Other definitional problems also arise. For instance, we will talk about the research team, even count the team members. This count reflects compromises, such as counting an oversight committee, some of whose members are noted as significant contributors to the research, as "1" member. Similarly, we had to arrive at judgments on counting graduate assistants (we did if they had thesis level involvement) and consultants (if they were significant contributors).

This chapter reflects our best resolution of such issues to characterize the 40 research projects. It is primarily descriptive and exploratory in nature, although we examine a few hypotheses (Table 1). The next chapter examines how well the 'STRAP' framework and imbedded hypotheses fit the 40 project data.

We note again that this empirical sample is purposive in nature, targeted on IDR. It cannot be considered representative of the five NSF programs as we selected peculiarly interdisciplinary projects. Those projects divide as follows among the five NSF programs involved:

1) Environmental Geosciences Program (7 projects)
2) Neurobiology Program (9)

3) Archeology (within Anthropology Program) (2)
4) Earthquake Hazard Mitigation, Societal Response Program (11)
5) Science and Technology to Aid the Handicapped (11)

We can observe 'how interdisciplinary' these 40 projects are in several respects (shortly, we will develop a composite factor of relative interdisciplinarity). Hypothesis 2, Table 1 posits that dramatic interdisciplinarity is really quite rare. While we don't have any exact measure of paradigmatic differences, our measures indicate that these projects really are interdisciplinary in a number of respects:

--45% included personnel outside the PI's grand disciplinary category (i.e., engineering, life sciences, physical sicences, social sciences, professional fields)

--median number of disciplines per team is 2.6

--60% judged to involve substantive expertise and techniques beyond a single research area

--only 12% of the PI's said their project was not IDR; 25% said narrowly so; 62% said it was IDR

--15% reported major intellectual barriers within the team and

--31% reported major differences in approach within the team.

Differences Among Research Organizations

The projects divide unequally among types of research organizations.

--Academic Department (24)
--Academic Ad Hoc Center (1)
--Academic Permanent Center (3)
--Non-Academic, Large, Departmentalized Organization (4)
--Non-Academic, Large Project--Matrix Organization (4)
--Non-Academic, Small, Fluid Organization (6)
--Other (1)

For some analyses we contrast academic department projects (24) with all others (16). It is surprising to note that a majority of these especially interdisciplinary projects reside with principal investigators (PI's) in academic departments. Some have charged that you can't perform IDR in academic line departments (some would say anywhere in academia). In fact, these PI's indicated less institutional opposition (but also somewhat less institutional support) for the research in question when associated with academic departments--See Table 3.

Certain academic areas seem more accepting of "IDR" research. For instance, our judgment of the degree of professional reward associated with performance of the research in question favored the more "academic department" (and also basic research) areas Archeology, Neurobiology, and Geosciences (83% of the sample projects in these programs were hosted by academic departments) indicated greater likelihood of professional reward for the research than Earthquake

Table 3

Differences Observed Between Projects Hosted by Academic Departments and Other Organizational Units

Variable (Levels)	Academic Departments	Other Organizational Structures[1]	Statistical Significance[2]
Type of Research (V9)			.05
- Basic	14	3	
- Applied	6	7	
- Policy	4	6	
NSF Facilitation of Funding (V36)(Mean) [Scale 0=No to 2=Major]	0.48	1.07	.02
Peer Review Rating (V49)(Mean) [Scale 1=Excellent to 5=Poor]	1.65	2.02	.03
Organization Support (V30)			.05
- Barriers Imposed	0	2	
- Neutral	14	4	
- Facilitated	10	10	
Our Judgment of Product Integration (V46)(Mean)	1.36	1.93	.05
Percent Team Outside the PI's General Disciplinary Category (V54)(Mean) [i.e., Life Sciences, Physical Sciences, Social Sciences, Engineering, or Professional Fields]	12.71%	26.75%	.06

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[1] Other organizational units collapse together all projects not administered through an academic department--academic ad hoc center (1); permanent academic center (3); large, non-academic organizations--with departmental structure (4) or with a project/matrix structure (1); small, fluid, non-academic structure (6); or other

[2] Statistical Test--Chi Square for cross-tabulations; One way Analysis of Variance for means [used even for ordinal measures here, although ANOVA assumptions entail interval measurement].

and Science and Technology to Aid the Handicapped (41% hosted by academic departments) [Overall analysis of variance (ANOVA) $\underline{F}$ test significant at $\underline{p}$ = .02]. Certainly, our project sample is too small in number, with so many factors to consider, to sort out all possible explanations for such differences. Nonetheless, the apparent openness to combining different research skills within the domain of acceptability to such academic departments stands out sharply against the sterotypical disciplinary narrowness.

This result suggests that one might classify academic departments (disciplines) in terms of their openness to intellectual infusion from other areas. We hypothesize that interdisciplinary basic research would be essentially unknown in 'closed' departments. We would go further to hypothesize that the utility of such disciplinarily 'closed' research would be far less than that in 'open' 'disciplines'. 'Openness' might be measured in terms of changes over time in the skills (STRAP framework) included in research projects. Research utility could be gauged by such measures as relative citation frequency (total and total outside the particular ISI speciality area--see Chubin et al., 1983). If future research were to support this hypothesis, it would provide one criterion for the relative allocation of research support among the 'disciplines'.

Table 3 shows other factors differentiated by research organization. Basic research is more likely to take place in an academic department; applied or policy research, elsewhere. Peer review ratings are correspondingly more positive for projects hosted by academic departments. Interestingly, PI's not nested within such departments were more likely to note NSF help in developing the proposal to receive funding. The picture that emerges is that NSF program managers need more actively to help proposers who fall outside established, academically based research areas. This helps to account for differences in apparent workload (number of projects monitored) between basic research programs and more eclectic applied/policy research programs.

Two features bearing particularly on interdisciplinarity differentiate academic departments from other organizational structures. As shown in Table 3, the latter are more apt to have more team members from outside the PI's general disciplinary category. The low overall percentage of such team members (17%, although 45% of these projects had at least one) in these projects selected for their interdisciplinarity reaffirms our sense that engagement of very different disciplines together in research is relatively rare. For instance a Neuroscientist requiring electronic skills will more likely acquire those skills than recruit an electrical engineer.[1] The 'STRAP' framework seeks to incorporate such realities by counting skills and gauging their distribution rather than cataloging the disciplines involved.

It would have been interesting to examine finer distinctions among research project organizations, but our sample could not support this. We did look at a number of other variables. Several that did not differ significantly between academic department and other organizational structures are of interest. The 24 academic department projects were not statistically distinguishable from the others in terms of:

--How interdisciplinary they are (V65)
--How many skills (substantive areas and techniques) entailed (V63)
--Team size (V14)
--Full time equivalent months of work involved in the project (V19)
--Likelihood of permanent vs. ad hoc teams (V18R).

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[1] R. B. Pinter of the University of Washington, Electrical Engineering Department, is an interesting counterexample. He studies neural processes, reporting his modeling developments to IEEE (1983b) and their physiological implications to the Society for Neuroscience (1983a).

In sum, sample projects housed in academic departments do appear about as "interdisciplinary" as those located elsewhere in many respects.

Seniority of IDR participants is another issue suspected to be related to academic mores. For one, Brian Mar postulates that teams involving very different seniority levels will function better. One very successful collaboration was attributed in part to a 20 year age gap. Our qualitative observations (we did not code participant seniority) suggest that assistant professors do not participate as heavily in cross-departmental work (note Hypothesis 1 of Table 1). However, in the Neuroscience and Geoscience cases particularly, assistant professors seemed heavily represented in our projects. Their labs were apparently quite 'open' to involving a broad spectrum of skills to tackle the problems of interest to them. This would seem to be well-reinforced by the acceptability of such research by their departmental peers. These research arrangements seem quite productive. They involve permanent labs and a single permanent researcher working with postdocs and doctoral students. This is complementary to Mar's observations (Purdue Workshop on Interdisciplinary Engineering Research, November, 1983) that graduate students from a range of departments can constitute very workable IDR teams under one senior researcher. It also suggests that Hypothesis 1 should be refined to suspect under-representation of assistant professors in IDR in 'closed', but not in 'open', disciplines.

Obviously, lack of professional reward is a potentially insurmountable hurdle to engaging junior researchers in IDR work. Such hurdles appear absent in areas such as Neuroscience and Geoscience. Our impression is that they remain prevalent in many traditional academic areas. Given our impressions that external research support is given prominent professional reward on many campuses, NSF program initiatives favoring IDR work could induce academic 'openness' in the longer term. In the short term, that might stress doctoral students, postdocs, and untenured faculty.

Projects Vis-A-Vis Interdisciplinarity

A major concern of the present study is to characterize projects in terms of how interdisciplinary they are, then to relate that to a number of other variables. Toward this end we collected data on a variety of factors that bear on "interdisciplinary."

As discussed in Section 2, a number of concerns prompt us toward a richer operationalization of this concept than simple accounting of the disciplines engaged. Toward this end we have gathered data on a variety of variables that relate in some degree to "interdisciplinarity." (See listing of variables in Appendix C.) We determined to employ factor analysis to ascertain whether these variables shared a common "interdisciplinarity" factor.

As the initial step in the factor analysis, we observed the correlations[2] among 14 variables, ran a preliminary factor analysis (using SPSS factor analysis--Statistical Package for the Social Sciences), and reconsidered conceptual links to "interdisciplinary." As a result, the list was winnowed to 8 variables, then to 7 which combined to yield a sensible general factor. Two of these 7 were set aside. The number of Institute for Scientific Information (ISI) categories spanned by prior team member publications (V55) suffered from missing data in 7 cases, partial

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[2]All exploratory correlations examined are Pearson product moment (r). The factor analyses and regressions are also based on such parametric statistics. Given our measurement uncertainties, violating the assumption of interval level measurement (many of our variables are ordinal) is not of undue concern. However, the more appropriate rho or tau values are reported where feasible.

data in most others, a relatively weak conceptual link to project interdisciplinarity, and low correlation with the general factor. Another variable, proportion of the total number of skills required on the project (S&T) possessed by the PI (V22) likewise suffered from a relatively weak conceptual link and low weighting in a regression on the general factor.

We thus settled on a 5-variable factor analysis, yielding the general "Interdisciplinarity" factor described in Table 4. This factor behaves quite robustly. It correlates well with not only its constituent variables (r or rho of .62 to .86), but even with V55 (rho =.24) and V22 (rho = -.50). Only 3 cases are missing. The distribution of cases on this "interdisciplinarity" factor (V65) is quite continuous, with no obvious cutpoints to distinguish interdisciplinary from disciplinary projects. Hence, the variable is analyzed as continuous, not discrete. Also, it provides an indication of how interdisciplinary one sample project is relative to another --not an absolute index.

V22 (extent of PI coverage of required skills) correlates negatively with V65 (the interdisciplinary factor). It does so also with measures such as the

Table 4

Variables Associated with How Interdisciplinary a Project Is

Categorial Variables Level (N)	Mean Value of Interdisciplinarity Factor[1] (V65)	Statistical Significance[2]
Type of Research (V9)		.0004
-Basic (17)	-.29	
-Applied (13)	.72	
-Policy (10)	-.58	
Principal Investigator's Grand Disciplinary Category (V51)		.047
-Life Sciences (9)	-.49	
-Social Science/Psychology (11)	-.26	
-Physical Science/Math (7)	-.04	
-Engineering (5)	.67	
-Professional Field (1)	.93	
Percentage of Team from Outside the PI's Organizational Unit (V62R)		.004
-Less than 40%	-.37	
-Greater or Equal to 40%	-.46	

Continuous Variables	Correlation with the Interdisciplinarity Factor[3]		Statistical Significance[4]	
	r	rho	r	rho
S&T Team Matrix Density (V25) (proportion of cells occupied in matrix of substantive areas and techniques required with team members)	-.63		.001	
Differences in Approach Noted Among Team Members (v32)	.53	.57	.001	.001
Intellectual Barriers to Team Interaction (V31)	.33	.37	.022	.013
Problem Revised (V34)	.28	.25	.045	.068
Peer Review Rating (V49)	.29	.23	.047	.095

[1] See text for discussion of computation. The formula is as follows for standardized variable values:

.21	V29	(interdisciplinarity in the view of the PI)
+.26	V53	(# of discrete disciplines represented on the project team)
+.36	V54	(% of team outside th PI's grand disciplinary category)
+.15	V57	(our graduate research assistant coder's rating of how interdisciplinary the project was)
+.19	V59	(range of skills--S+T)

[2] One way ANOVA, probability levels for _F_ test.

[3] These ordinal scaled variables are treated as if they were continuous, interval scaled in these tabulations: V29, V57, V59, V32, V31 V34, V49. Rho provides a more appropriate measure of correlation than the Pearson product moment correlation coefficient (r) for such measures.

[4] One-tailed t-test probabilities.

number of disciplines represented on the project team (V53; r = .63). This is interesting in that some practitioners feel that the PI should possess expertise in all the skills involved. One sizable team project claimed that everyone involved had multiple areas of expertise. However, more generally these projects suggest that one typically utilizes team research to bring in skills not mastered by the PI. (A counter-possibility might have been that teams were engaged to have sufficient manpower to complete the research in limited time periods, but that it not supported by the data.) Where the PI does not possess all the requisite research skills, 'hub and spokes' communication (wherein team members interact mainly with the PI) and integration of findings by the project leader may not be advisable strategies (see also Rossini and Porter, 1979). Indeed, only 15% of the PI's categorized themselves as using this approach to integration. Unfortunately, our evidence on research products and their integration is too weak to test hypotheses such as #3 and the second part of #4 in Table 1. This suggests that team IDR will entail relatively complex group dynamics. Social factors as well as intellectual ones will not be easily set aside.

Table 4 presents other variables pertaining to how interdisciplinary a project is. The finding that applied research, in the professions, such as engineering, tends to be more interdisciplinary in nature is intuitively appealing. Surprisingly, policy studies among these projects scaled least interdisciplinary. It must be cautioned though that the nuances of the small sample of 40 projects from 5 specific NSF programs loom important in such tabulations. The observation that projects with more team members from outside the PI's organizational unit tend to be more interdisciplinary is also intuitive, but quite important. This implies that any epistemological difficulties will be compounded by organizational hurdles. Interdisciplinary research issues confound with inter-departmental or inter-institutional research issues. Investigation of the intellectual and the organizational issues should be continued in order to guide research management.

The second portion of Table 4 also offers several interesting findings. First, the research skills (S&T) by team member matrix tends to be relatively empty for more interdisciplinary projects (Figures 1 and 3 illustrate such cases). Project integration strategies such as common group learning (wherein everyone becomes expert in all skill areas) (Rossini and Porter, 1979) seem poorly suited to these cases. Further research in terms of S&T matrix characteristics may provide useful insights into team formulation and management. The next three variables catalogued in Table 4 reaffirm the complications in IDR. More interdisciplinary projects tend to have more intellectual differences among participants and to revise the research problem somewhat more than do less interdisciplinary teams.

Table 4's final bit of information supports another suspicion (Hypothesis 4 (first part) of Table 1) -- that peers review such proposals more harshly. We can't say if the more disciplinary proposals were "better." Again, we must note this is an observation on only 40 specific projects. That all are funded (and selected as interesting) suggests that anti-interdisciplinary biases might be even stronger for a cross-section of all proposals, funded and not. That is speculation. NSF might want to examine a random sample of nonfunded and funded proposals to see if this effect holds generally. If it does, this should be taken into account in the funding process.

We can note also some variables not significantly associated with how interdisciplinary a project is (V65):

--Whether the project is new or a continuation (V8)

--Whether there is an advisory committee (V47)
--Project duration in months (V7)
--Full time equivalent total months for the team (V19)
--PI proportion of the full time equivalent months for the project (V20)
--Prior team experience (V26)
--Whether NSF facilitated funding (V36)
--How productive the project was (V45, V64)
--The total number of skills (S&T) required (V63).

We also attempted to distinguish variables that associated with project output. Our weighted sum of research products (V64) correlates (rho = .49) with our judgment of how productive each project was (V45). Nevertheless, as noted in Section 3, our ability to measure research outputs <u>comparably</u> across these projects is severely limited.

We did not find any strong predictors of productivity. Project status (V60), as to whether the project is complete, does not seriously affect the weighted sum of research outputs. Size of the project (in full time equivalent team months--V19) correlates only .15 (non-significant). Neither the disciplinary grand category of the PI nor the judged availability of professional reward for the research predicts research output. The interdisciplinarity factor and other measures of how interdisciplinary a project is do not associate significantly (e.g., r between V64 and V65 = -.08). Peer review ratings also fail to anticipate the quantity of research output ($r = -.04$). The only slightly suggestive positive finding is that the presence of an advisory committee is associated with greater output (Mean of 11.8 vs. 7.8 without an advisory committee, $p = .13$), but no strong conceptual linkage exists.

Hypothesis 5 (Table 1) is not supported--production is non-significantly higher the more novel the project is for the research organization (V6). However, there is some support for Hypothesis 6. Prior experience together (V26)is associated with greater research output (non-significantly) and with higher research output/full time equivalent team effort ($p = .0045$).

5. EXPLORATION OF THE 'STRAP' FRAMEWORK

The descriptive results of the previous section support the viability of the 'STRAP' approach in several instances. We now turn explicitly to examination of our a priori notions (Table 2) in terms of the 40 project empirical base.

Our most basic premise is that we can operationalize the five components of the 'STRAP' framework--Substantive Areas (S), Techniques (T), Range of S&T's (R), Administrative Unit Complexity (A), and Personnel Configuration (P). We first address S&T--the novel ingredients--then the others.

The "S&T" notion is predicated on the belief that one does not compose a project team to solve a research problem by collecting representatives of a set of disciplines. One does not 'need' an earth scientist, or even a geophysicist. Nor does one just need a single answer to a known question (e.g., What is the likelihood of a magnitude 7 quake in Los Angeles by the year 2000?). One needs expertise in seismic patterns for the southern California area. Similarly, one does not need an economist, nor a person who knows how to operate a given simulation program. One needs an economic modeler facile with the sort of simulations pertinent to forecasting building stock risk estimates from earthquakes. There is a level of skill definable--whether substantive area or technique--that one needs. These "atoms" of skill for an IDR project should reside within single individuals, and they should not be readily decomposed into smaller units.

We knew of no precedents in attempting to measure these skills (the closest is the use of subdisciplines, c.f. Darvas and Haraszthy 1980). We thus began with our intuitive judgment and tested this with the respective PI's. Our pilot test on 6 projects found that the PI's did not totally relate to our concept. However, in the main sample interviews with a revised format, they did. To a surprising and gratifying degree, they seemed to know what we were talking about and to be able to relate to the S&T's. By and large they accepted our listings. But they also made significant corrections and amplifictions. Five samples of the resulting profiles of skills and team participants appear as Figures 1-5. The S&T framework certainly bears refinement, but it appears workable.

Table 5 presents summary statistics on the S&T tabulations. The typical project counts a little over

Table 5

Skill Requirements--Substantive Areas and Techniques (S & T)

Variable	Median	Mean	Standard Deviation	Minimum	Maximum
Sum of S&Ts	6.12	6.40	2.57	1	16
- Ss	3.30	3.25	1.58	0	8
- Ts	2.70	3.15	2.21	0	9
Expert Level (Level 2) S&Ts	4.28	4.40	2.52	1	16

6 skill areas--about equally divided between substantive areas and techniques. We learned that perusal of participant backgrounds for their skills was not a foolproof way to ascertain who contributed what to the project. "Interdisciplinary" learning can be important to the individuals and to the project. For instance, participants with a given skill may not actively employ it on a particular project. Conversely, participants lacking a skill may acquire and use it during the course of a given project.

There is some violation of our first hypothesis (Table 2) that

--Always at least 1 technique and 1 substantive area can be identified.

One project contains no S's. NSF provided support to purchase equipment to be shared among independent researchers. We delimited "the project" to not include separately funded projects of the investigators. Hence, this instance does not refute the hypothesis. (It does illustrate the pitfalls in partitioning research into analysis units!) Four projects coded by one of us did not differentiate any techniques. This reflects a coding problem. The skill areas were too aggregated and did not break out techniques from substantive concerns. Coding criteria for S&T should be refined, and the hypothesis reevaluated on other projects.

We also attempted to differentiate skills by the level of expertise needed. Level 2--"frontier expertise"--may be required, or, Level 1--"journeyman, technician"--may be enough. Again, PI's generally related clearly to this distinction, evidencing this by correcting our initial classifications (roughly at an average of 1 or 2 per project). More than 2/3 of the skills identified were rated Level 2.

In general, we are very pleased with the operationalization of the S&T measures. We should also point out some difficulties. Especially in policy research, it was sometimes awkward to decide what skills were involved. Sometimes, one could pinpoint a skill with fair confidence, yet not know whether to label it S or T (e.g., "integrative modeling" in Figure 5). The judgment between Levels 1 and 2 was not always comfortable.

An important operational issue was whether two independent raters could code skill requirements consistently. We contrasted the 20 projects coded by ALP with the 20 others coded by FAR. Of 9 S&T tallies, only 3 showed notable differences:

--Level 1 techniques (technician level) (V13) --
means of 2.20 and 0.65 (t test, signficant at
p = .001,2-Tail)

--Sum of S&T's (V63)--means of 7.15 and 5.65
(p = .066)

--S&T by team matrix density (V25)--means of 46%
and 57% (p = .064)

The generally good agreement implies that the S&T classification scheme is workable. The only statistically significant disagreement is in the number of "technician level" techniques coded (that difference corresponds to the observed difference in the sum of S&T's also). More precise rater criteria should be devised for future studies of the 'STRAP' framework.

The split between levels in the S's and T's is intriguing--

Skill	Level 2	Level 1
S	2.7	0.6
T	1.7	1.4

We see relatively few instances of journeyman substantive knowledge skills identified. Possibly "Level 1" substantive expertise (S) exists as background knowledge not explicitly logged. It would be interesting to examine a representative sampling of projects across various research areas to see if such patterns hold. To the extent they do, they bear possible important information for research training, the development of technicians with needed skills, and IDR team configuration. For instance, should "Level 1" techniques be learned directly by researchers who possess "Level 2" substantive expertise?

We were interested in whether the sum of S&T's (V63) correlated with selected other variables. A small positive correlation with communication pattern density V27) (r = .27) suggests a possible link between a greater number of skill areas and greater team interaction.

Observing linkages between S&T patterns and IDR performance would be of most interest. Due to the limitations in our data base with respect to measuring output, we prefer to be cautious. We can, however, examine a number of "process" hypotheses on this project sample. In so doing, we use split samples wherever appropriate.

We hypothesized that:

> At least 1 S or 1 T will demand high expertise unless they reflect a cross-"paradigm" synthesis. (Hypothesis 2, Table 2)

The data support this. Level 2 skills (S or T) average 4.4 (median 4.3) per project, ranging from a low of 1 in the case of 3 projects to a high of 16 in 1. The modal values are 4 or 5 Level 2 skills per project (9 instances of each).

Another hypothesis asserted:

> Complexity in terms of S&T can be measured; it will not correlate simply with a tally of the number of disciplines represented on the core team. (Hypothesis 3, Table 2)

This is supported by the absence of significant correlation between the sum of S&T skills (V63) and the number of disciplines represented on the project team, or core team (see Table 6). This supports the hypothesis and implies that the S&T skill accounting does not simply track with the number of discrete disciplines represented on the team. (None of the observed small correlations are significantly different from zero.)

A more intricate hypothesis holds that:

> Problems requiring substantive expertise in two or more areas are more likely to need collaboration than problems requiring technique expertise in two or more areas. (Hypothesis 4, Table 2)

Stated another way, this means that individuals are more apt to acquire advanced skills in multiple

Table 6

Correlations Between S&T Characteristics and Other Team Features
(Pearson Product Moment Correlations)

	Sample 1 N=20	Sample 2 N=20)	Whole Sample N=40)
Sum of S&T Skill Areas (V63) with:			
N Disciplines--Core Team (V52)	.07	-.02	-.02
N Disciplines--Whole Team (V53)	-.12	.15	.07
Level 2 Substantive Expertise Areas (V10) with:			
N Participants--Core Team (V15)	.12	-.12	-.02
N Participants--Whole Team (V14)	.07	.33	.15
Level 2 Technique Expertise Areas (V12) with:			
N Participants--Core Team (V15)	-.17	-.30	-.21
N Participants--Whole Team (V14)	-.33	.19	-.00

techniques than in multiple substantive areas. We reasoned that this should reflect in a higher correlation between V10 (Level 2 substantive expertise areas required) and number of participants (V14, team size; or V15, core team) than between V12 (level 2 technique expertise required) and number of participants. While none reach statistical significance, Pearson correlation coefficients are more positive for V10 than for V12 with each of V14 and V15 in Sample 1, Sample 2, and the whole sample. The 4 independent correlations (i.e., for Samples 1 and 2, with V14 and V15) differ on average by .25. This supports the hypothesis. It appears that we can begin to dissect research collaboration in terms of S&T skills. This sort of approach promises to provide useful insight into the nature of "IDR" and possible mechanisms to enhance it.

Let us now turn to the other 'STRAP' dimensions. "Range" of skills derives from examination of the S&T entities. Qualitiatively, we tried to map how remote the various skills (S&T) for a given project were from each other. This did not yield very satisfactory results. We fall back on the summary variable, V59, then as a gauge of range. This variable reflects our judgment as to whether the S&T's (1) lie within an established research area, (2) lie within a single grand disciplinary category (e.g., life sciences), or (3) span grand disciplinary categories. Coding yielded relatively fewer entries in the middle category (7) than in the other two (16 and 17 entries respectively). In fact, one often faced a choice between (1) and (3). For instance, in the Science and Technology to Aid the Handicapped program, some research focused on computer-aided speech processing. At some point in the evolution of research in this area, this would certainly represent (3) -- spanning grand disciplinary categories. Psychologists and professional fields such as speech and hearing came together with computer scientists, electrical engineers, and modelers. Then, at some past or future point, one could conclude that the requisite skills had been within a research area of computer-aided speech processing--thus implying a (1) coding for V59. Adoption of seemingly remote skill areas is also observed especially in the neurosciences.

We examined a pair of hypotheses (5 and 6, Table 2) pertaining to range--

(5) Rarely will basic research cross paradigms.

(6) Development work and policy research is far more likely to warrant crossing paradigms.

A. "Research" continuity is less and crossing paradigms is a larger task in these areas, hence collaboration is more suitable than single individual learning.

B. Permanent teams would have a great advantage over ad hoc assignments given the difficulties in welding effective teams of this nature, but this demands provision of research continuity.

While we don't have a measure of paradigm as such, we can look at range (V59) as well as percent of research team outside the PI's grand disciplinary category as indicators.

Table 7 shows the results. Both variables distinguish basic from applied research in both samples. Basic research is less "interdisciplinary" in nature. The position of policy research is not so clear from these results.

Sub-hypothesis "6A" can be addressed in terms of V8 and V18. V8 (stage of research support) should be lower in non-basic research areas. This pattern does not appear significantly for sample 1, but it does for sample 2 (and for the whole). We thus have some indication of greater continuity of support in the basic research areas. V18 (permanence and configuration of the research team) would also be expected to be greater in basic research projects. Visualizing single researcher and lab arrangements together, this pattern can be seen in both samples,

Table 7

Contrasts Among Basic, Applied & Policy Research

Variable Examined	Sample 1				Sample 2				Whole Sample			
	Basic	Applied	Policy	Significance	Basic	Applied	Policy	Significance	Basic	Applied	Policy	Significance
Number of Projects	8	8	4		9	5	6		17	13	10	
Range of Skills (V59)	1.4	2.5	2.5	.023	1.9	3.0	1.3	.0035	1.6	2.7	1.8	.0034
%Team Outside PI Grand Category (V54)	7.2	44.2	26.2	.0043	7.3	30.0	0.0	.0135	7.3	38.8	10.5	.0001
Stage of Research (V8)				.35				.0345				.0095
-No Directly Prior	2	2	3		0	3	4		2	5	7	
-Prior, Not NSF	3	4	0		1	1	0		4	5	0	
-NSF Continuation	3	2	1		8	1	2		11	3	3	
Personnel Configuration (V18)				.02				.17				.0789
-Single Researcher	2	0	0		0	0	1		2	0	1	
-Lab (Quasi-Permanent Team)	5	1	3		3	0	0		8	1	3	
-Ad Hoc Project Team	1	7	1		6	5	5		7	12	6	

NOTE: Values are means. Statistical significance indicates the probability level for *F* test of the one way Analysis of Variance (V54, V59) or for Chi Square (V8, V18).

although not statistically significant in sample 2 (or for the whole).

It is fascinating to wonder whether more permanent research support for enduring policy and applied research teams might not increase their productivity. We examined whether product integration was better with other than ad hoc project teams. Recalling the weakness of our product measures, the results are still provocative. Sample 1 showed no significant differences, but sample 2 did, reflected in the whole sample as well--

<u>Relative Degree of Product Integration</u>

Single Researchers (N = 2)	1.0
Lab or Quasi-Permanent Teams (11)	2.1
Ad Hoc Teams (23)	1.4

The overall <u>F</u> test is significant ($p = .04$). However, this result supportive of Hypothesis 6B is highly tentative given the absence of significant differences in sample 1 and the measurement weaknesses. A comparison hypothesis (#7, Table 2) anticipated higher outputs for ongoing projects (V8). This was not observed at a statisticlly significant level for either sample.

We also explored the hypothesis (#8, Table 2) that:

> As project skill requirements increase in complexity, interpersonal and organizational dimensions become more important determinants of project success.

While again emphasizing the limitations of our measures of project success, we found no significant evidence of such an interaction effect between the sum of S&T (V63) and organizational support, intellectual barriers, or differences in approach (V30, V31, V32) in predicting performance (in terms of V45, V46, or V64).

Moving to the "A" in 'STRAP,' our main measures are the percent of the project participants from related units (i.e., in the same overall organization -- V16) and the percent from unrelated units (V17). We add these to give the percentage outside the PI's immediate unit (e.g. lab, department) (V62). For some purposes we truncate this into projects with relatively few (under 40%) from beyond the immediate organization (N=24) and those with 40% or more outsiders (N=16). This count, in itself, indicates the considerable degree of organizational complexity associated with these heavily interdisciplinary projects. At a more detailed level, 12 of the projects had no participants outside the PI's immediate unit. Overall, the mean is 32% (median, 33%).

The percent of participants outside the PI's unit (V62) correlates with intellectual complexity in terms of S&T stretching beyond a research area (V59)--r=.485. It does so to a lesser degree with the sum of S&T skills involved (V63) r=.24.

We posited that teams with 40% or more from outside units would be more likely to meet organizational barriers. Such a relationship did not appear at all--

% Outside PI's Unit	Organizational Support (V30)		
	Barriers Imposed	Neutral	Facilitation
Less than 40%	2	10	12
40% or More	0	8	8

It is reassuring to note how little organizational resistance was pointed out by the PI's.

The sole a priori hypothesis examined on organizational structure (#9, Table 2) was :

> Organizational constraints on collaboration may impede solution of complex research problems.

We tested two regressions on weighted production (V64) with V63 (sum of S&T skills involved) and either V30 (organizational support) or V62 (% outside PI's unit) and the interaction terms. In neither were the interaction terms (nor V30 and V62) significant. So, we can only note the considerable extent of organizational complexity in these projects, but little evidence of it interfering with the conduct of the research.

"P"--Personnel Configuration--is the final 'STRAP' factor. We categorized teams as single researcher, quasi-permanent team (lab), or ad hoc team. The majority of the projects are ad hoc, with only 3 single researcher (Table 8).

We examined the hypothesis (#10, Table 2) that:

> Permanent or quasi-permanent research teams will be more productive than ad hoc teams.

As shown in Table 9, for each of the three "productivity" indicators examined, results were statistically significant for one sample, but not for the other. There seems to be a tendency for quasi-permanent teams to be more productive.

Table 8

Productivity Comparisons Among Different Personnel Configurations (V18)

Variable Examined	Sample 1				Sample 2				Whole Sample			
	Single Researcher	Quasi-Permanent (Lab)	Ad Hoc Team	Significance	Single Researcher	Quasi-Permanent (Lab)	Ad Hoc Team	Significance	Single Researcher	Quasi-Permanent (Lab)	Ad Hoc Team	Significance
Number of Projects	2	9	9		1	3	16		3	12	25	
Product Integration (V46)	1.0	1.8	1.9	.53	1.0	3.0	1.2	.0027	1.0	2.1	1.4	.04
Judgment on How Productive (V45)	1.5	2.3	1.4	.11	1.0	3.0	1.5	.044	1.3	2.5	1.5	.0055
Weighted Sum of Products (V64)	4.0	13.7	3.6	.0003	19.0	5.7	9.6	.40	9.0	11.7	7.4	.27

Another hypothesis explored (#11) was:

> It is easier to solve a development problem by partitioning it into discrete problems than to partition a problem in basic research.

We only examine the whole sample because our indicators do not directly address the decomposition question. Table 9 finds that the S&T by team member matrix is less dense for applied research than for either basic or policy. Likewise, communication pattern intensity is less (though not statistically significant). These essentially descriptive findings nonetheless suggest that the hypothesis may be on the mark--that the nature of interaction must fit the problem, and that this varies systematically across research types.

Table 9

Team Interaction Comparisons Among Basic, Applied and Policy Research (V9)

Variable Examined	Basic	Applied	Policy	Signif
Number of Projects	17	13	10	
S&T Coverage-Core Team Density (%) (V24)	60.1	48.0	71.3	.006
S&T Coverage-Team Density (%) (V25)	52.3	41.6	62.2	.033
Communication Density-Core Team (% Possible Strong Links) (V27)	71.1	63.7	82.0	.27

6. INTERDISCIPLINARY RESEARCH MANAGEMENT

We now step back from consideration of interdisciplinary research processes in the conduct of particular projects to address more global research management issues. To this end, we describe the NSF programs with whom we interacted significantly. Peer review, a major concern in IDR management, is then assessed empirically for the 40 project--5 program sample. Drawing on perspectives gathered from discussions with the project PI's, NSF Program Managers and our own reflections, we then raise specific points for NSF consideration and then for research organizations themselves.

NSF Programs Considered

We spoke with cooperative NSF program managers whose programs seemed interdisciplinary in character in our attempt to draw out the factors that make a difference in successful IDR performance. The Environmental Geosciences program is a young venture reflecting the continuing specialization of substantive knowledge and techniques within geology. This $1.6 million program in fiscal year (FY) 1983 handles geoscience research projects focused at or near the surface of the earth. Archeology is a program area with a thirty year tradition of interdisciplinary interaction among anthropologists, botonists, zoologists, and geologists. The three areas of archeology, physical anthropology, and cultural/social anthropology had a $5.6 million budget for FY '83. Some two hundred proposals per year are received in the archeology and physical anthropology areas together. Cognitive Science is an emerging new area whose researchers still identify primarily with their old disciplinary roots (e.g., cognitive psychology). The memory and cognitive processes program had a budget of $2.3 million for FY '83. Because Dr. Young considered most all of the research projects to be disciplinary, within a cross-disciplinary program, we did not pursue the investigation of individual projects. The Neurosciences effort at NSF has grown to about $22 million for FY '83 divided among molecular and cellular neurobiology, developmental neuroscience, integrative neuroscience, sensory physiology, and psychobiology efforts. We focus primarily on the Neurobiology program within this area.

Both of the two targeted research programs addressed, Societal Response to Earthquake Hazards and Science and Technology to Aid the Handicapped (STAH), had directly legislated mandates. The earthquake effort is of particular interest as a social science effort within the Engineering Directorate; its budget runs on the order of $2 million per year. The Science and Technology to Aid the Handicapped program has had an on-again, off-again financial existence, in the off mode for FY '83, completing projects previously funded (on again in FY '84). Neither of these programs represent a clear cut professional area of identification. <u>Technology Assessment</u> at the time that we studied projects in that area was quite new, but did have a nascent professional identification. Its budget reached several million dollars per year at its peak.

Certain of the projects included in these programs also involved the Industry/University Cooperative Research or the Small Business Innovation programs. In addition, our perceptions are enriched by our own miscellaneous interactions as researchers with the Divisions of Science Resources Studies, Social and Economic Sciences, Mechanical Engineering and Applied Mechanics, and by the broad perspective of our sponsors on this study, the Office of Interdisciplinary Research.

The programs observed vary widely on project demographics. Proposal funding rates range from about 15% to 40%. The number of proposals handled varies dramatically from, maybe, 25 per year to 200 per year, per program manager. Collaborative team research involving persons identified with different disciplines ranged from an estimated 10% to 33%. In particular it was very low in Geosciences and Neurobiology (both basic research programs), yet the program managers with whom we spoke perceived that <u>much of their single investigator research had an interdisciplinary character</u>. We agree that interdisciplinary research is not restricted to team research. While the nature of projects differs in important ways between basic and targeted research programs, even basic research can be problem-focussed, requiring multiple substantive areas of knowledge and techniques.

Peer Review of IDR Projects

One of the greatest concerns raised about interdisciplinary research projects is that they not fall through the cracks of organizations designed for disciplinary research. Indeed, one PI explained how a program decided his research really didn't belong--after funding it for 3 years. At that point, where does one turn? (Fortunately, in this instance another NSF program stretched to accept the work.) With NSF's essentially disciplinary organization, especially for basic research, the possibility of unequal treatment for IDR arises. Peer review is a focal point of concern in the management of IDR.

Basic intellectual topics are not necessarily bounded by historically constituted disciplines. For example, Archeology is concerned not only with human societies, but also with the fauna, flora, climate, and geology of the site being investigated.

With this being the case, we investigated the reception that the 40 projects in our sample received from peer reviewers. We were sensitive to general attitudes toward IDR projects. We also considered possible differences according to the intellectual and professional orientations of reviewers and principal investigators, and between basic and applied/policy research. Indeed, the analysis of our data yields some provocative findings.

Table 10 shows the distribution of peer review ratings by program. In all, we obtained 247 usable ratings, including individual reviews and individual ratings on panel reviews, on 37 funded proposals. Each

Table 10

Peer Review Ratings by Program and General Category

Program	Proposals (N)	Reviews (N)	Rating[1] (Mean)	Standard Deviation
Geoscience	7	41	1.68	.80
Neurobiology	9	54	1.42	.59
Archeology	1	7	1.14	.38
Earthquake	9	73	2.05	.95
Sci & Tech Handicapped	11	72	2.05	.98
Total	37	247	1.82	.90

[F = 6.90, $p < .0001$]

[A priori t test - Geoscience & Neurobiology vs Earthquake and Sci & Tech-Handicapped 4.55, $p < .001$]

General Disciplinary Category[2] of Reviewer	Reviews (N)	Rating (Mean)	Standard Deviation
Physical Science	34	1.79	.75
Life Science	43	1.55	.86
Social Science	48	1.88	.95
Engineering	34	2.12	.95
Professional Fields[3]	35	2.09	.99

[F = 2,56m p = .04]

[1]Ratings scaled from 1=Excellent to 5=Poor.

[2]Following the National Research Council categorizations of doctoral scientists.

[3]Includes Urban & regional planning, disaster specialist, business administration, education, law, library & information science, social work, speech & hearing, broadcasting, administration and related fields.

proposal averaged 6.7 reviews, ranging from means of 5.9 to 8.1 for the 5 programs. (One proposal yielded only a single review; one, 17 reviews).

The striking feature of Table 10 is that the ratings among these funded proposals differ significantly among programs. Likewise, they differ significantly if one looks at the general disciplinary category of the reviewers. Naturally, reviewers' general disciplinary category is closely associated with program. What one sees is that basic research proposals rate more highly than applied or policy proposals. One could speculate on the underlying reasons--possibly, such projects are inherently stronger, maybe basic researchers are more competent (see also Brooks, 1978). Alternatively, there is the suspicion that reviewers are just more comfortable with basic research endeavors.

A related finding highlights the seriousness of the rating difference among programs. Differences among ratings are better explained by program (F = 16.17, p .001) than by individual proposal differences (F = 2.06, p = .15). That is surprising, even among a set of funded proposals.

To pursue the implications further, this suggests that it will be easier for basic scientists to obtain favorable ratings in NSF peer reviews. Unless NSF compensates for this, it follows that basic scientists will find it easier to obtain funding than will other applicants. A conversation with one PI illustrates the potential distortion. His project was funded without hassle by a scientific program; it had earlier been flatly rejected by an NSF engineering program. Obviously, one such experience or a tally across 40 selective, funded proposals cannot be definitive. Representative sampling of funded and declined proposals across a spectrum of NSF programs would be useful to pin down the degree of such bias.

Table 11 indicates a comparable leaning toward academic researchers. This is consistent with a favoring of basic research. It also confirms a suspected NSF inclination toward support of academic research. Possibly most interesting is that we find no evidence of higher ratings for PI's residing in line academic departments than in other organized academic research units. One must keep in mind that this set of proposals was selected as being especially interdisciplinary in nature. Also, again no surprise, the science proposals were more apt to emanate from

Table 11

Peer Review Ratings by PI Affiliation

PI Organization	Reviews (N)	Rating (Mean)	Standard Deviation
Academic Department	103	1.71	.82
Academic-Intermediate Department/Center	34	1.43	.63
Academic Center	24	1.60	.84
Quasi-Public Funder of Research	20	2.45	.87
Large Consulting Firm	33	2.03	1.02
Small Consulting Firm	28	2.15	1.02
Quasi-Public User of Research	5	2.20	.84

[F = 4.66, p = .0002]

[a priori t test of academics vs. all others yields t = 4.29, $p < .0001$.]

academic departments than the engineering ones.

We also examined whether reviewers differed in their average ratings according to their organizational affiliation. They do not in any systematic manner ($\underline{F}$ = 1.38, $\underline{p}$ = .20). Neither grouping of academics vs. others, nor of researchers vs. users showed any significant differences, thus supporting Hypothesis #7 (Table 1).

To probe this further, we categorized reviewer affiliation as academic or not, and also categorized reviewer discipline as 'traditional' or not. (Examples of traditional include electrical engineering, chemistry, sociology. See Appendix C with peer variable listing for details.) Neither variable elicits a statistically significant difference in rating levels (both yield $\underline{F}$ levels with $\underline{p}$ < .15). However, both do show small differences in the anticipated direction. On average, academic reviewers graded proposals .14 units more favorably; traditional disciplines, .17 units more favorably (overall ratings average 1.82 with a standard deviation of 0.90). Unfortunately, our sample tends to contain mainly interdisciplinary proposals so that it is not possible to contrast views on IDR work with 'traditional' disciplinary work.

Hypothesis #8 (Table 1) is not quantitatively operational in this study. However, we can offer a sharp impression. Researchers engaged in areas such as the Neurosciences appear to meet less resistance from their peers (proposal reviewers and professional reward evaluators) for performing 'IDR' work than do those in 'traditional' disciplines. As mentioned earlier, some research areas appear more 'open' to using techniques and even substantive expertise not historically wedded to their area. The selected reviewer comments to which we were privy, pertaining to interdisciplinarity, were rarely critical. One economist reviewer faulted a proposal for including non-economic aspects. More typically, one found calls for adding a particular skill to the project team. On occasion, a reviewer would indicate reluctance to grade the proposal other than in his or her own domain of expertise. Our general sense was that Neuroscientists and Archeologists, in particular, did not need to justify their inclusion of 'outside' skills. Problem dimensions seemed to mandate certain needs and one strove to cope with those. On the other hand, other areas, especially in NSF programs with which we are familiar beyond those included in this empirical study, meet grave resistance in reaching beyond disciplinary bounds.

Table 12 presents the most intriguing finding in this examination of peer review of IDR proposals. As per Hypothesis #9 (Table 1), one could anticipate reviewers favoring that to which they are dedicated. Table 12 confirms this suspicion. The results are not only highly significant for both operationalizations of disciplinary match, they are generated within the narrow confines of a set of funded proposals. This xenophobic effect will work against support for interdisciplinary research. It cautions against the simple strategy of composing a review team by including 'someone who knows this area, someone else who knows another area,' until we span the whole proposed project. The present results suggest that review strategy will generate poorer review ratings than would result from a review team conversant with the research as a whole.

Given that this sample of projects and programs is oriented toward interdisciplinarity, we were still curious to see if the 'more' interdisciplinary projects rated as highly. To this end we observed the correlation between the interdisciplinarity factor (V65, main project file, not peer file) and peer rating

Table 12

Peer Review Ratings by Disciplinary Similarity of PI and Reviewer

Disciplinary Match[1]

Degree of Match	Reviews (N)	Ratings (Mean)	Standard Deviation
Same	76	1.69	.85
Similar	52	1.68	.80
Different	67	2.21	1.00

[F = 7.61, p = .0007]

General Disciplinary Category Match[2]

Same	112	1.73	.86
Different	82	2.07	.98

[F =6.70, p = .01]

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[1]Our judgement based on information available on PI and Reviewer.

[2]Mechanical comparison of the general disciplinary grouping (physical science, life science, social science, engineering, professional fields, or arts and humanities--as per National Research Council codes) of the PI and Reviewer.

(V49). The correlation is in the direction of more interdisciplinary projects being down-rated. It is significantly so for the first sample of 20 projects ($r = .50$, $p = .02$); but non-significantly so for the second sample ($r = .16$, $p = .26$). The whole sample is also significant ($r = .29$, $p = .047$). If one includes information on program (V4), then the interdisciplinarity factor is swamped and is no longer a significant predictor of rating. So, overall, we find partial support for the notion that interdisciplinary proposals tend to rate lower. This should be studied further on a full sample of disciplinary as well as interdisciplinary proposals, both funded and declined.

As a final probe into what determines high peer ratings, we regressed peer rating on five candidate predictors in our peer data file (See Appendix D on peer listing)--whether the PI is academic or not, whether the Reviewer is academic or not, general disciplinary category match between PI and Reviewer, PI general disciplinary category (ordered from basic science to applied), and Reviewer general disciplinary category. Stepwise regression shows academic PI as the significant predictor of high rating ($F = 16.38$, $p < .001$) with Category Match second, but not statisticlly significant ($F = 2.56$, $p = .11$). (Analysis of variance yields similar conclusions.)

If these findings generalize across NSF, then some of the fears expressed formally and informally by members of the research community have merit (c.f., Cole et al., 1981; Carter, 1982). Peer reviews appear to favor research performed by academics, especially in the sciences, within the reviewer's own domain of expertise. Compensatory mechanisms to counterbalance these inclinations may be warranted.

Issues in NSF Management of IDR

Table 13 summarizes some general project differences among the sample of projects from 5 NSF programs. Again, one should not forget that this sample emphasizes 'IDR' work and is not intended to be respresentative of the NSF programs more generally. Nevertheless, the differences are of interest. While it is not always straightforward how to delimit projects, it seems quite clear that projects in Neurobiology and Archeology tend to stretch longer than the two years typical of the other three programs. Likewise, the full time equivalent (FTE) professional time is considerably greater (although with high variability in Neurobiology). Ongoing support is more typical of the science programs involved than of the other two, especially the Earthquake program. Both duration and scale constraints could hinder IDR. Lastly, non-academic PI's are more likely to be supported in the Engineering Directorate programs.

We should also note several variables that do not distinguish among the programs significantly. Research productivity appears particularly high in the small sample of Archeology projects included, but the other four programs don't show consistent differences on

Table 13

Some Project Differences by NSF Program

Variable	Overall (40 projects)	Geosciences (7)	Neurobiology (9)	Archeology (2)	Societal Response to Earthquakes (11)	Science and Technology to Aid the Handicapped (11)	Significance (Probability Level)
Project Duration (V7) (Total Months)	28.8	24.9	36.0	48.0	24.1	26.6	.03(F)
Total Full Time Equivalent Team Effort (V19) (Months)	57.8	26.1	105.4	149.5	36.9	43.3	002(F)
PI Situated (V5 Recorded):							
-Academic Department	24	7	7	1	4	5	.05 (Chi^2)
-Other	16	0	2	1	7	6	
Prior Related Work (V8)							
-No Directly Prior	14	2	1	0	8	3	.04 (Chi^2)
-Prior, Not NSF Supported	9	1	3	0	0	5	
-NSF Continuing Support	17	4	5	2	3	3	

weighted output sums or on the basis of our judgments. The division of project effort is quite consistent across the five programs with PI's accounting for an average of 26% of the FTE support.

Table 14 indicates certain variables pertaining to 'interdisciplinarity' that differ among the five NSF programs. Archeology projects (small sample of 2) tend to the largest project teams. Personnel configuration ('P' in the STRAP model) tends to 'ad hoc' arrangements for projects supported by Geoscience and STAH: to permanent teams for Neurobiology and Archeology. In terms of likely professional reward for the research in question, the anti-IDR tendencies show up most in the two applied programs. This occasions our reconsideration of academic departments. Rather than lump them generally as hostile to IDR sorts of activities, we suggest it may be more fruitful to classify them as 'open' or 'closed' to IDR--with Archeology and Neurobiology, and, to a lessor extent, Geoscience, quite open.

One indicator of how interdisciplinary a project is would be the percentage of the research team affiliated with disciplines relatively distant from that of the PI (e.g., social science from life science from

Table 14

Interdisciplinary Research Project Differences by NSF Program

Variable	Overall (N=40)	Geoscience (7)	Neurobiology (9)	Archeology (2)	Societal Response to Earthquakes (11)	Science and Technology to Aid the Handicapped (11)	Significance (probability level)
Project Team Size (V14)	5.6	6.1	4.6	11.0	5.1	5.6	.04 (F)
Personnel Configuration (V18 Recorded)							
- Lab or Single Investigator	15	1	7	2	4	1	.0005 (Chi^2)
- Ad Hoc Team	25	6	2	0	7	10	
Apparent Degree of Professional Reward for the Work (V48)[1]	1.3	1.6	1.8	2.0	0.8	1.2	.02 (F)
% of Team from Outside the PI's Grand Disciplinary Category (V54)	18.3	12.3	0.0	19.0	14.7	40.6	.0004 (F)
Total N of Skill Areas Represented on the Team (S&T) (V63)	6.4	6.1	6.4	12.5	6.3	5.5	.007 (F)
Interdisciplinarity Factor[2]	-.15	-.06	-.70	.44	-.35	.50	.04 (F)

[1] Scaled: 0 = Nil, 1 = Minor, 2 = Major

[2] A weighted function of 5 variables pertinent to interdisicplinarity: .21 (interdisciplinarity in the view of the PI) + .26 (# of discrete disciplines represented on the project team) + .36 (% of team outside the PI's grand disciplinary category) + .15 (rating of how interdisciplinary the project is) +.19 (range of skills--S+T).

engineering...). On such a measure, the STAH program projects reach far beyond the others in our sample. On another measure, the total number of skill areas represented, the Archeology projects stand out from the others. On our composite interdisciplinarity measure, STAH and Archeology are highest; Neurobiology, lowest. Given the difficulties attendant to generating, reviewing, and monitoring IDR, NSF might want to measure the relative interdisciplinarity of its programs and take this into consideration in the allocation of research management resources. Were one committed to such problem-solving research, the degree of interdisciplinarity might even be considered a positive sign for a program.

Our conversations with NSF Program managers and PI's on the 40 projects provide a number of useful thoughts as to ways to bolster IDR at NSF. A wide variety of creative support mechanisms have been generated. The following list stimulated by discussion with Steven Kornguth (Neurobiology Program Manager) suggests potential innovations in a variety of programmatic contexts:

(1) Single investigator grants wherein that individual bridges multiple substantive techniques (e.g., the primary mechanism in the Neurobiology program.

(2) The multi-disciplinary team wherein several people work together toward a common end, but their contributions are relatively independent (e.g., requiring substantial interaction among the participants holding different substantive knowledge and/or techniques).

(3) Separate grants to individuals at a single institution who really intend to work as an interdisciplinary or multidisciplinary team (a mechanism known in the Neurosciences area as a counter to the resistance to proposals over, say, $100,000).

(4) Special set-asides for particular groups (e.g., Archeology providing a competition every three years for radio carbon labs for physicists and chemists).

(5) Funding of special state-of-the-art studies by individuals to stimulate new research directions.

(6) Special programs to help individuals learn a new technique (e.g., set-asides for researchers to spend a year learning a new technique needed for a particular research endeavor).

(7) Multi-user equipment grants, wherein researchers with basically independent interests get together to have capital and possibly operating expenses supported for a shared piece of equipment (e.g., a protein purification lab that some would use for work on viruses, others for cell membrane studies).

(8) Supporting special topic conferences to bring together different substantive knowledge bases and skills (e.g., Geosciences supporting the Penrose conferences on topics such as the origin of life).

We can comment on several of these possibilities. Recall that an aim is to solve the problem expeditiously; the single person project has a major advantage in being fundable at a much lower dollar level (e.g., $50K per year). The composite knowledge skills accrued by the single researcher are also portable, whereas the research team can suffer a severe loss if one of its key members leaves. A strong disincentive to the individual acquiring all the necessary substantive and technical skills is the huge opportunity cost and commitment entailed. Furthermore, one certainly cannot handle some large problems, or problems of high urgency, by a single individual project.

The one example suggested to us to be of the form of suggestion 3, 'quietly collaborating,' turned out much less so in the eyes of the researchers themselves. Collaboration was not active, although some possibilities for the future were mentioned. In general, cross-lab collaboration, when reported, seemed typically short-term. We did learn of one dyad who began with separate labs at separate universities, one moved to the other's university, and their still-separate labs collaborate extensively. More often, 'cross-lab collaboration' meant learning a new technique in another's lab. But the agenda is then to take that technique back to one's own lab to work on one's own problem.

Investigators noted the 'Catch-22' nature of trying to expand their skills to tackle problems of interest. One investigator reported a proposal low-rated by NIH because the technique was not already set up and going (the main point of the support request). Another shared his personal experiences in acquiring new techniques. These entailed learning from another, collaborating enough to establish a bit of a track record (bootlegged on old support). Only when a problem is already solved, or on the very brink, dare you request support. You can't get research support to get into anything new! You have to demonstrate you already can do it or have essentially done it. Reviewers demand so much detail that it makes methodological flexibility very difficult. The contrast, in these respects, between the basic science areas we examined and policy areas is particularly sharp. Possibly, the basic science review process should be loosened, in some cases, to encourage technique transfer.

Suggestion 7 (equipment sharing) shows a checkered pattern. We heard horror stories about trying to use 'their' equipment in sharing a facility at another university. On the other hand, another investigator reported favorably on sharing equipment (NSF support grant to 3 institutions) situated at the same other university. In two cases, we heard of equipment sharing (protein purification in one, electron microsope in the other) leading to some substantive collaboration that had not been planned. So, equipment sharing appears quite attractive in terms of efficient use of scarce resources and potential cross-fertilization, but delicate in terms of demanding on-going technician support arrangements and clear commitments to sharing.

One might conceive of carrying equipment sharing and cross-lab collabortion further--for investigators of comparable seniority and complementary skills to share a lab. It would seem an empirical question as to whether such research forms might be more effective than conventional single senior investigator lab arrangements. Conversely, those managing applied and policy research might consider support arrangements that would allow single investigators to invest the time and energy to acquire a constellation of skills to tackle problems that have heretofore required team research.

Several program managers mentioned that they or their panels would, on occasion, suggest team additions to a PI. At least one of our teams reported that they had added an M.D. to the team at NIH urging. In the eventual absence of NIH support, the M.D. was not interested enough to participate in the NSF-sponsored project. This suggests that mandating additional team, or oversight panel, participants is no guarantee of real interaction.

We wondered how representative proposals are of actual team participation. We asked the PI's to provide information on who actually engaged in the research. The hunch was that actual project teams would differ markedly from those named in proposals, due to a combination of over-generous inclusions in proposals to look more interdisciplinary and actual turnover. To the extent that such is the case, review of proposals in terms of IDR participation is undercut. Results, however, are really quite encouraging--65.6% of those named in proposal and/or actual team work are common to both (with no significant differences across the 5 NSF programs).

Another appealing way to foster IDR would seem to be to suppport work in research organizations most conducive to it. That suggests inclusion of other than traditional academic settings, especially small, flexible research organizations (c.f., Rossini et al., 1981). The targeted research programs appear in principle to lend considerably more support to non-academic researchers. However, we note some opportunities for such support in the basic research directorates (e.g., Archeology support for museum research; Cognitive Science support for non-academic work). Several small business organization PI's expressed reservations about NSF support. Slow turn-around on proposal review can be lethal for small firms who must plan use of their resources more closely than larger firms and universities. More than one PI felt NSF antipathy toward non-academics. The first words one heard form his replacement program manager were "you'll never get any more money for this as long as I have a stake." Two pointed out an NSF misperception that they are subsidizing business, who would otherwise have to pay their own funds for the research. On the contrary, one PI expressed his firm's sense of stretching to engage in the work, beyond any sense of practical returns to itself. The waiver of matching requirements for small business was seen as vital.

Monitoring of research progress and outcomes could provide useful feedback to tune project selection and support mechanisms. There is strikingly little technical interaction between program managers and PI's.

On a scale of 0 = No Technical Interaction, 1 = Minimal, and 2 = Major, 37 PI's assessed the extent of post-funding technical interaction at a mean of 0.27. There were significant differences among the programs ($F = 6.40$, $p = .0007$); Societal Response to Earthquake was high at a mean of .89; Geoscience and Science and Technology to Aid the Handicapped low at 0. Program managers thought that monitoring might be best concentrated on the more complex projects, i.e., IDR types. Researcher workshops, such as have been used in the past in Technology Assessment program, might prove useful.

At least two PI's suggested that NSF take a more active hand in dissemination of results. This would be especially helpful for IDR work, particularly for non-academic researchers. It would bolster the NSF image by showing the fruits of the research support.

Within a program, or even a division, program managers touted open interchange and funding flexibility among the programs as important in fostering interdisciplinary research support. A small number of program managers working together with a perception of a common pool of funds to be allocated facilitates openness to projects that might overload one of their programs or fall between the cracks. In the small number of programs we interviewed, such a pattern of sharing of funds seemed more common in the basic research areas. It would also seem desirable in targeted research areas where larger scale projects would tend to make for "lumpier" funding. Such close collegial association among program managers in the related areas seemed to have helped the Neurosciences remain functional at NSF during a period of tremendous growth. Pulled together through a working panel in 1971 as Neurobiology, this research was later split into several programs, using the vehicle of experimental panels to test the waters. Program managers report that the resultant split programs have not lost their ability to work together to serve the full Neuroscience area.

The need for program managers to interact effectively would seem to speak for career appointments. On the other hand, the Neurosciences have used rotaters deliberately to infuse new substantive area/technique expertise into the program by drawing in new blocks of reseachers and widening the reviewer/panel pool. Changes and recent specifications in research areas also argue for rotaters.

A point made by several managers is that interdisciplinary projects tend to be large in terms of required levels of support, and these are therefore more difficult to support, particularly for basic science programs with model grants on the order of $50,000-$60,000 per year. Funding one such project means declining several additonal single investigator projects, or venturing into the difficult terrain of seeking joint funding. One reviewer in an applied program explicitly criticized one of the proposals as too large. Dr. Redman notes that interdisciplinary support may actually be on the wane now, not because of intellectual reasons, but because of costs--IDR projects get enormously expensive and the program can't handle that.

Joint funding can be, and is, accomplished. A general principle put forth is that increasing the administrative interaction required decreases the likelihood of success. It requires the active effort of the program manager to set up reviews and obtain joint funding. This means if either program manager involved (more than two would surely worsen the odds even faster) is particularly busy, it would be tough to spare the time to provide special handling to the odd-fitting proposal. The further afield the joint sponsorship falls (e.g., between directorates), the more difficult the task. One counter to this is for a program to adopt other disciplines within its scope and provide support to them as well, as Anthropology has done quite regularly for zoologists and biologists on Archeology teams (they also sometimes jointly fund with environmental biology). To reduce the extent of "double jeopardy," mechanisms such as the second program's agreeing on reviewers and providing a representative to look over the project seem preferable to co-review with more than one panel shooting at the proposal.

Joint funding with other agencies is reported as quite rare. The sense conveyed to us was of awareness of what each agency is doing in a research area with modest levels of cooperation and little or no sense of competition. Slightly different focii can often be distinguished, as with the National Institute of Health's tending toward clinical Neuroscience research and NSF not (though it was noted that 60% of the proposals are submitted to both agencies). Where one source of funding for a research area dries up, the other agency may stretch its perceived emphasis to try and accommodate the researchers otherwise left out (e.g. NSF Geosciences picking up some research from the Environmental Protection Agency, NSF picking up Cognitive Science from the National Institute of Education). The Neurosciences noted a year-old interagency working group among NSF, NIH, and the Department of Defense. All-in-all, overlap in coverage of research areas is desirable to foster interdisciplinary research by providing multiple chances at finding support for the out-of-the-ordinary proposal.

Issues Outside NSF in Management of IDR

One PI offered the following 5 pointers for IDR--

1. The mission should truly require more than one discipline.
2. You need a mechanism to protect each field's professional sovereignty.
3. Hold frequent staff meetings of the whole team.
4. Provide adequate support staff able to tolerate the range of professionals involved.
5. Provide mechanisms for academic units to carry out research independent of departments.

Another observed that one advantage in performing IDR at a large university with slightly overlapping departments is that you have multiple chances to get people together. Others have made an analogous observation concerning multiple possible sponsors being particularly helpful for budding IDR projects.

Another researcher perceived a 'secret' of his successful IDR work in the 'scientific socialization' involved. This long-running, large team enlisted lots of pressure to complete assignments on those wishing to remain involved, with dramatically successful results--essentially no components unfinished in 15 years.

On a more 'micro' level, it is interesting to contrast the individual spans of skills embraced in IDR work. Figures 1-5 show instances wherein researchers overlap skills heavily and others where they neatly complement each other.

Certain Neuroscience labs contained Ph.D. students and post-docs, all with access to the same set of skills. In one case Ph.D.s from one lab often became postdocs in the other, and vice versa. Applied projects in the Engineering Directorate in our sample were more likely to bring together individuals with distinct skills. Such differences bear not only on research performance, but also on training.

We have already noted the Neuroscience mode of skill-acquisition wherein one 'bootlegs' learning in another's lab. Such efforts are described as typiclly residing outside formal funding relationships. On the other hand, post-docs provide a 'legitimate' vehicle to learn a fresh set of techniques or substantive areas.

IDR in such a guise stands in stark contrast to the typical Ph.D. narrowed training venue. Also, the collaboration among distinct practitioners was described to us as beneficial in cross-pollinating one's own perspective and research agenda.

<u>Other Factors Influencing Non-Routine Problem-Focused Research</u>

NSF research policies (and dollars) exert a pull on researchers to address certain sets of problems. This study has examined a sample of NSF-sponsored projects to see what factors aid 'IDR.' In the course of the study, we came upon other forces affecting the development of interdisciplinary research areas. We share these observations here.

<u>Professional societies</u> would seem to be candidates to mold research initiatives, but we did not hear reports of their playing critical roles in this. Certainly, special interests within existing professional associations do evolve and do provide a meeting ground for coalescing research interests. Starting a new professional association goes even further in this regard. However, none of the NSF program managers or other individuals with whom we have spoken pointed toward such efforts as critical to

stimulating an interdisciplinary research area.

Within the Neurosciences, two specific ventures were noted for their role in stimulating this area. Frank Schmidt of MIT formed Neuroscience research programs that pulled elites together for two to three days to work on a particular interesting problem. The Sloan Foundation supported the initiation of Ph.D. programs in some 25 to 30 schools in the 1970s by offering about $350,000 per year on the condition that a Neuroscience group had to be pulled together. The resultant interaction stimulated research interaction as well.

As touched upon elsewhere, one attractive solution in conducting interdisciplinary research is to use non-academic settings. One seemingly needs to reward elimination of barriers to interaction due to departmental loyalties and so on. Technology Assessment groups in small, flexible organizations seemed more suited to such collaborative research (Rossini et al., 1981). Unfortunately, our empirical base from which to discuss non-academic interdisciplinary research is extremely limited (see the bibliographic essay, Volume II).

Turning to the academic setting, the basic problem of rewarding interdisciplinary research is all too well known. It typically is accorded low prestige and finds acceptable publication outlets lacking. Two models of this academic process may yield insights and suggest possible counter actions.

The 'Serf' model sees the faculty member as bound to the department. Peer evaluation is performed by the discipline of that host department. Tenure lies there and is extremely hard to shift. Even if one becomes Dean or President of the University, he or she remains a professor of whatever, retaining tenure in the same department. Joint appointments prove disconcerting to the disciplinary barons so that a joint responsibility becomes no one's responsibility. Research that does not fall neatly within the baron's bounds is deemed too difficult to evaluate and hence is accorded no value worth mentioning. Thus, the 'Serf' had better serve his or her discipline to survive.

The 'Pimp' model portrays faculty as whores with administrators as pimps. The pimp's prime objective is to sell the services of the whores, namely through externally supported research. Pimps sometimes compete among themselves within a university for dollars and territory. For instance, a Dean Pimp would frown upon one of his whores engaging in a reseach project that fell in the domain of another dean pimp. Sometimes, pimps perceive sponsors as their own, and fight others within their university off, realizing that any money pot is limited.

To the extent that there is a grain of truth in these two caricatures, how can one reduce the barriers to interaction within the university setting? Georgia Tech uses a sub-project budgeting model which placates administators by sharing overhead among the different units whose faculty members are participating in the study. That helps resolve the Pimp model dilemmas, but not the Serf model side. Full resolution may require moving to some sort of a matrix model. It would seem that we could distinguish three functions: research, research training, and service instruction. Research centers differentiated from instructional departments may be a vehicle if a different form of peer review and tenure arrangement (maybe the five year rolling contract in lieu of tenure) can be arranged. Anatomy departments provide another model wherein their whole research orientation, in many cases, is shifting to Neuroscience while their service instruction mode continues to include gross anatomy, etc. (Rossini et al., 1984). This allows some interesting professional arrangements. For instance, we have been told of departments hiring non-anatomists on the basis of needing particular research techniques, with the understanding that they can pick up enough to provide the service instruction. Ph.D. anatomists routinely take postdoctoral appointments in non-anatomy departments and, conversely, anatomy departments offer post-docs to non-anatomists. This runs quite counter to the traditional Serf model. One might wonder if the university of the future would allow such practical, multi-skill requirements for research to overcome the narrow disciplinary criteria of many Arts and Sciences departments. One could imagine problem-driven research in, say, the social sciences, becoming quite disassociated from disciplinary service courses offered.

An intriguing intellectual/institutional issue emerges when a research area considers departmentalization. Biochemistry illustrates the situation where enough people in a common area brought in enough research money to warrant their breaking off to establish departments. The counterexample is provided by the Neurosciences where, despite common interests and research money, there has been very little move to departmentalize. The apparent discriminator between these two cases is the general university financial climate, much tighter during the era of Neuroscience growth.

Tight budgets exert another force. Namely, they present a choice between cutting all schools, say 15% and selectively cutting out a number of programs so as to provide strong support for selected "Centers of Excellence." The rationale in favor of the latter is that it takes a critical mass to bring to bear the necessary range of substantive knowledge and techniques to effect high quality research and training. This notion is consistant with a much broader perspective on interdisciplinarity wherein mutual enrichment takes place well beyond the bounds of single projects or even of identifiable collaborations (e.g., co-authorship of papers).

7. CONCLUSIONS

Effective interdisciplinary research (IDR) means solving complex problems by bringing to bear multiple research skills. It is difficult--for program managers, for reviewers, and for researchers. However, it often defines the cutting edge of science and engineering. Directing new techniques at the resolution of tough problems offers the greatest prospect for intellectual breakthroughs. The important societal problems of today do not fit within historical disciplinary bounds.

The National Science Foundation (NSF) has proved to be an important stimulator of such research by identifying promising areas and drawing researchers into them. But it can do more by actively considering the special difficulties attendant to IDR. Toward that end we offer three sets of recommendations.

First, we suggest that existing conceptualizations of 'IDR' have been too constricting. We offer the 'STRAP' framework to point toward what we see as the critical dimensions of 'IDR'--

--Problem-focussed Research

--Requiring the Combining of Multiple Skills (Substantive Expertise and Techniques)

--And Demanding Special Consideration of Organizational Features.

This empirical study of 40 NSF projects demonstrates that the STRAP framework is understandable to researchers and leads to testable hypotheses on how to tackle complex problem-oriented research. In so doing it should help in expanding research management attention to 'IDR' beyond academia. It also opens new problem-solving strategies to consideration. For instance, the Neuroscience single (senior) investigator model for IDR might find useful application in certain applied or policy research areas. Conversely, the ad hoc team made up of individuals with distinct skills might enrich certain basic science 'IDR' work.

Second, as we focus on how best to solve problems requiring multiple skills, we should pay heed to the issue of how best to train researchers for this task. NSF research grants and possible training initiatives can be a strong influence on academic training. For instance, post-doctoral support could be made contingent on the applicant's making the case that the experience will provide a new technique that (s)he plans to employ later to address some research problem. Or, NSF might stimulate more basic structural changes in academic research approaches. For example, making equipment funds contingent on sharing the resource among senior researchers could help instigate more integrated research than evidenced in the fiercely independent, individual lab model so predominant. Such a stragegy would most likely affect students experiencing such sharing, and not yet having their own labs. Another possibility for training more conducive to IDR is the interdisciplinary PhD program, as exemplified by the 70 or so cross-disciplinary Neuroscience Ph.D. programs.

Third, we can suggest some actions within NSF that might foster multi-skilled, problem-focussed research. NSF must recognize its own organizational resistances to such IDR. Its programs largely model academic disciplinary foci. As such, IDR work must surmount special hurdles, and that means special assistance is needed. Natural forces work against IDR support when proposals are not encouraged from their beginnings, when program budgets temper against large projects, and when joint funding requires considerable extra initiative and effort. Program managers who work closely together and perceive a somewhat 'joint' budget among themselves (rather than strictly separate program budgets) could most easily guide 'in-between' proposals over the cracks between programs. Neurosciences and

Anthropology are each seemingly able to work such strategies within their respective domains. Perhaps, NSF might set aside some fraction of all program budgets for joint research ventures.

The review process presents special hurdles for IDR work that cannot be ignored if problem-focussed work is to prosper. As we document here, one can expect lower ratings of a proposal that stretches beyond a reviewer's disciplinary base. That implies that gathering a disjointed array of reviewers to cover all the bases of an IDR proposal dooms it to an expected lower rating. Obviously, multiple panel review heightens such concern. To give IDR proposals a fair chance, one must either search for reviewers who each possess sufficient breadth and commitment to the research area to do it justice, or lower rating standards in comparison to proposals in established domains. Another possibility might be to incorporate a feedback round into the review process. Such a 'Delphi' like process could entail an opportunity for PI's to respond to mail reviewer comments, with those comments and other reviewer comments fed back to the original reviewers, who would only then provide their proposal ratings. This would give the individual reviewer a better perspective on the proposed project and a chance to resolve concerns due to unfamilarity with certain aspects. That such an approach might help is supported by some panelist comments to the effect that they "changed their mind after discussion."

In sum, NSF must lend a helping hand to overcome the natural biases against IDR. Academic reseachers whose own performance evaluation depands on disciplinary peers risk a lot to engage in IDR. NSF can nudge academics toward 'openness' by indicating priority to fund proposals that evidence novel skill combinations designed to solve cogent problems. Loosening peer review demands for such explicit research protocols that the research must almost be already done would help in this regard. On the non-academic side, NSF might work to reduce its perceived anti-business bias. Small business set-asides, speedy review, and help through the proposing process are the sorts of actions our sample PI's appreciate. If we are right in crediting problem-focussed, multi-skilled research (IDR) with the highest research payoff potential, then NSF should actively foster it, for it cannot compete equally on its own in the present organizational climate.

Figure 1

S&T Matrix for a Large Project (Archeology)

Team Members (by Discipline)

S (Substantive Area) or T (Technique)	Skill	Level of Expertise 1 = Journeyman 2 = Expert	1) Prehistorian	2) Anthropologist	3) Prehistorian	4) Geologist	5) Archeologist	6) Archeologist	7) Illustrator	8) Botanist	9) Geologist	10) Botanist	11) Paleontologist	12) Archeologist (Ph.D. Student)	13) Archeologist (Ph.D. Student)	14) Chemist
T	Archeological Survey	2	X	X	X		X	X						X	X	
S	Geological Mapping	2			X	X					X					
T	Pollen Analysis	1								X						
S	Neolithic Adaptation	2	X	X	X		X	X								
T	Statistical Analysis	1	X													
T	Botanical Analysis	1										X				
S	Faunal Analyses	2											X			
T	Excavation	2	X	X	X		X	X						X	X	
T	Artifact Analyses	2	X	X			X	X						X	X	X

Figure 2

S&T Matrix for a Small Project (Geosciences)

Team Members (by Discipline)

S (Substantive Area) or T (Technique)	Skill	Level of Expertise 1 = Journeyman 2 = Expert	1) Soil Genesis	2) Chemist	3) Soil Chemist	4)*Soil Chemist (M.S. Student)	5)*Soil Chemist (M.S. Student)
T	Organic Chemical Soil Analyses	2		X		X	X
T	Inorganic Chemical Soil Analyses	2	X		X	X	X
T	Soil Sampling	2	X			X	X
S	Forestry	1	X				
S	Soil Genesis	2	X		X	X	X

* Each GRA on for a 6-month period (hence S&T team density computed on basis of 4 team members (V25).

S&T Matrix for a Several Phase Science & Technology to Aid the Handicapped Project

Team Members (by Discipline)

S (Substantive Area) or T (Technique)	Skill	Level of Expertise 1 = Journeyman 2 = Expert	1) Artifical Languages	2) Technician	3) Rehabilitation	4) Linguist	5) Business Administration	6) Psychologist	7) Electrical Engineer	8) Center for Disabled	9) Electrical Engineer	10) Software Engineer	11) Hardware Engineer	12) Psycholinguistics
T	Interview Disabled Consumers	1			X					X				
T	Interview Others	1			X					X				
S	Voice Output	2	X			X	X	X		X	X			
T	Prototype Construction	2									X	X	X	
S	Evaluation	2	X		X							X		
T	Simulation	1	X								X			

S&T Matrix for a Lab Project (Neurosciences)

Team Members (by Discipline)

S (Substantive Area) or T (Technique)	Skill	Level of Expertise 1 = Journeyman 2 = Expert	1) Neurologist	2) Cell Biologist (Post doc)	3) Neuroscience (Ph.D. Student)
T	Mammalian Single Cell Preparations	1		X	X
T	Intracellular Recording	1	X	X	X
S	Cell Electrophysiology	2	X		X
T	Voltage Clamps	2			X
T	Statistics	1			X
S	Synaptic Transmission	2	X		
S	Inontophoresis (Pharmacology)	2	X	X	X
T	Mini/Superfusion	2		X	X
S	Neuropeptides	2	X	X	
S	Opiates (Neuropharmacology)	2	X		X

Figure 5

S&T Matrix for a Committee Study (Earthquakes)

Team Members (by Discipline)

S (Substantive Area) or T (Technique)	Skill	Level of Expertise 1 = Journeyman 2 = Expert	1) Policy Analysis (Exec. Secy)	2) Policy Analysis (Staff)	3) Communications (Chair)	4) Disaster Studies (Comm. Member)	5) Communications (Consultant)	6) Communications (Consultant)	7) Disaster Studies (Consultant)
S	Disaster Studies	2	X	X		X			X
S	Mass Media	2	X	X	X		X	X	
T	Policy Analysis	2	X	X					
T	Workshop	1	X	X	X		X	X	
T	Interviews	1			X		X	X	
T	Content Analysis	1			X		X	X	
T	Field Studies	1			X		X	X	
S	Integrative Modeling (Conceptual)	2	X			X		X	X

<u>References</u>

Birnbaum, P.H. (1979), "A Theory of Academic Interdisciplinary Research Performance: A Contingency and Path Analysis Approach," <u>Management Science</u>, Vol. 25, pp. 231-242.

Brooks, H. (1978), "The Problem of Research Priorities," <u>Daedalus</u>, Vol. 107, Spring, pp. 171-190.

Carter, G.M. (1982), "What We Know and Do Not Know About the NIH Peer Review System," The Rand Corporation, Santa Monica, CA, June (N-1878-RC/NIH).

Chubin, D.E., Porter, A.L., Rossini, F.A., and Connolly, T. (1983). <u>Indicators of Interdisciplinary Research</u>, report to the National Science Foundation, Division of Science Resources Studies.

Cole, S., Cole, J.R., and Simon, G.A. (1981), "Chance and Consensus in Peer Review," <u>Science</u>, Vol. 214, 14 Nov, pp. 881-886.

Darvas, G., and Haraszthy, A. (1980), "A Comparative Study of Interdisciplinary Research Areas in Poland and Hungary," <u>Management of Research, Development and Education, IV International Conference Proceedings</u>, Wroclaw Technical University, Wroclaw, Poland, pp. 31-40.

Enzer, S., Some Impacts of No Fault Automobile Insurance--A Technology Assessment, Report R30, Institute for the Future, Menlo Park, CA.

Friedman, R.C. and Friedman, R.C. (1983), The Role of University Organized Research Units in Academic Science, Pennsylvania State University, University Park, PA (report to the National Science Foundation).

Kash, D.E. (1977), "Observations on Interdisciplinary Studies and Government Roles," in, <u>Adapting Science to Social Needs</u>, Scribner, R. and Chalk, R. (eds.), American Association for the Advancement of Science, Washington, DC, pp. 147-167.

Pinter, R.B. (1983a), <u>Proceedings, Society for Neuroscience Annual Meeting</u>.

__________. (1983b), "Neural Computation: The Electrophysiological Bases for Product Operators and Consequences for Wide-field Textured Inputs," Proceedings of the International Conference on Systems, Man and Cybernetics, IEEE-SMC, Bombay, India (Jan 3, 1984), pp. 93-97.

Porter, A.L., Rossini, F.A., Chubin, D.E., Connolly, T. (1980). "Between Disciplines," Science, Vol. 209, p. 966 (29 August).

Rossini, F.A. and Porter, A.L. (1979). "Frameworks for Integrating Interdisciplinary Research," Research Policy, Vol. 8, pp. 70-79.

Rossini, F.A., Porter, A.L., Kelly, P., and Chubin, D.E. (1981). "Interdisciplinary Integration Within Technology Assessments," Knowledge, Vol. 2, pp. 503-528.

Rossini, F.A., Porter, A.L., Chubin, D.E., Connolly, T. (1984), "Cross-disciplinarity in the Biomedical Sciences: A Preliminary Analysis of Anatomy," Proceedings of the Second International Conference on Interdisciplinary Research, Pearson, A. et al. (eds.), John Wiley, London.

Rossini, F.A., Porter, A.L., Kelly, P., Chubin, D.E. (1978), Frameworks and Factors Affecting Integration within Technology Assessments, Department of Social Sciences, Georgia Institute of Technology, Atlanta, GA (report to the National Science Foundation).

Teich, A.H. (1979), "Trends in the Organization of Academic Research: The Role of ORUs and Full Time Researchers, in Proceedings of the First International Conference on Interdisciplinary Research Groups, Barth, R.T. and Steck, R. (eds.), Interstudy, c/o University of Washington (D. Baldwin), Seattle, WA, pp. 244-259.

White, I.L. (1975), "Interdisciplinarity," in, Perspectives on Technology Assessment, Arnstein, S.R. and Christakis, A.N. (eds.), Science and Technology Publishers, Jerusalem, pp. 87-96.

APPENDIX A

Interdisciplinary research redefined: Multi-skill, problem-focussed research in the STRAP framework

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Abstract

A new framework for the study of interdisciplinary research processes is presented. 'STRAP' emphasizes the combination of identifiable skills—substantive knowledge and techniques—that must come together to solve a complex research problem. This framework holds promise of better accommodating non-academic settings and yielding new insights into the management of complex R&D projects.

DEFINITIONS AND DIFFICULTIES

We have commonly viewed interdisciplinary research (IDR) as the melding of component contributions from several disciplines to solve a research problem. The requirement that these contributions be internally and substantively linked served to distinguish IDR from the often practised multidisciplinary research in which the components were linked only externally, and from 'transdisciplinary' research, an ideal type in which the components were subsumed under a single intellectual framework that overarched the disciplines involved and thus integrated them. Definitions by Nilles (1975), Petrie (1976), Meeth (1978), and others are in essential agreement.

In recent years there have been a number of studies of such research processes, predicated on the belief that IDR is the appropriate mode to attack many of the most interesting and challenging problems. Indeed many of us became interested in the study of IDR because we saw problems of great intellectual and societal interest cutting across scholarly and professional disciplines. We challenged disciplinary science as too restrictive as a general concept of science, even as dull and useless in some cases (Rossini, 1979; Chubin, 1983). However, it appears to us now that we and others may have missed the mark by emphasizing the 'discipline' in interdisciplinarity, and falling into other errors that we will now discuss.

First, we have been entrapped by thinking of disciplines. The very definition of IDR that we use implies that it consists of interactions among intellectual disciplines. But what are these disciplines? Intellectually, disciplines represent historical, evolutionary aggregates of shared scholarly interests. For example, in our small study of anatomy departments (Porter, 1983; Rossini *et al.*, 1984), we found that anatomy has been revolutionized by microchemical techniques and has shifted its substantive concerns overwhelmingly to neuroscience. In this case, the disciplinary label remains, but the content has been drastically altered.

Kuhn (1970) posited that a common intellectual framework or 'paradigm' distinguished a mature discipline. Yet humanistic clinical psychologists and behavioural clinical psychologists have no such common pϕaradigm while most experimental solid state physicists and physical chemists share such a framework. Darden and Maull (1977) pointed toward a central problem as a distinguishing feature of a field (in their work, field is nearly synonymous with discipline). However, not even in the most homogeneous fields is a single research problem dominant. In another attempt, Petrie (1976) differentiated disciplines by their use of different observational categories. Yet different disciplines often share observational categories (e.g. energy transitions in physics, chemistry, and biology), while sub-subdisciplines may differ (e.g. as in the two clinical psychology areas noted).

These problems reflect the difficulties of identifying 'discipline' in an empirically acceptable manner. If abstract knowledge cannot readily be pigeon-holed, individuals with 'impure' backgrounds and interests are

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equally difficult to categorize. One of us (Rossini) has a Ph.D. in physics, an academic appointment in philosophy, and a major research commitment to various facets of technology and science policy. Were he to work on a team with a sociologist (included in his academic department), would that constitute interdisciplinarity? With a physicist?

A second pitfall into which we have fallen is to assume that IDR implies collaboration so as to have 'disciplines' to interrelate, ignoring the possibility of individual IDR. This assumption followed the views of Petrie (1976) that individual IDR 'is simply out of the question for most people, given the demands of time and energy placed on obtaining even one disciplinary competence', and of Taylor (1975) that the individual interdisciplinarian, the 'ideal polymath', does not exist. On the contrary, a case can and will be made that complex research problems can sometimes be better tackled by individuals.

A third temptation of which we are aware, but have found hard to resist, is to restrict the focus of the study of IDR implicitly to academia. Not only do academics parade the clearest disciplinary labels by their advanced degrees, they also reside in administrative structures with the same names. As a consequence, we may blur intellectual and organizational considerations in studying academic research. We also tend to miss many intellectual and organizational problems that arise in the context of the industrial and government research laboratory (Mar *et al.*, 1983, private communication).

In sum, by concentrating on a version of IDR that emphasizes disciplines, groups, and academia to the exclusion of reasonable alternatives, we appear to have constricted our focus to a single, narrow research process in a generally adverse setting. To escape from this bind, we propose a new operational conceptualization that can generate new hypotheses on how to perform research on complex problems more effectively.

MULTI-SKILL, PROBLEM-FOCUSSED RESEARCH: THE STRAP FRAMEWORK

We propose to relabel IDR and beyond that to develop a framework with operationalizable variables to describe it and to deal with its dynamics. The central assumption that we adopt is the problem dominance of research, by which we mean simply that every research project is designed to solve a problem that is bounded to some degree by disciplinary concerns, societal interests, or other mechanisms. Our emphasis is on problems that require complex intellectual and/or organizational solutions.

We have considered several alternatives to the notion of discipline. What has emerged is the notion of intellectual skills. We distinguish between two types of skills: substantive knowledge of some area and techniques. Substantive knowledge is about something (e.g. molecules containing carbon, bees, the Politburo), while techniques are systematic approaches to generating and processing knowledge (e.g. statistical analysis of data, particle acceleration, dissection). Many techniques can be used to study the same substantive area while many substantive areas can be addressed by the same technique. If we are serious about using these concepts, then we need to operationalize them effectively so that they can be used in place of the unwieldly 'discipline'.

In sketch, substantive area can be described operationally by identifying a subject of knowledge to which some research community can relate. The area can be broad or narrow, but it must be sufficiently limited so that one individual can maintain in-depth competence in it. While this description leaves gray areas and less-than-clear cases, it provides a beginning for our purposes. A technique can be described operationally as a physical and/or intellectual procedure that may result in the generation or transformation of knowledge. A technique must also be such that an individual can become expert in it, and it must be useful in the solution of at least some class of research problems.

The relation between intellectual skills and disciplines appears to be a complex one. As noted earlier in the case of anatomy, and in the striking case of twentieth century physics, the substantive areas and techniques dealt with by the disciplines have changed over time. Some substantive areas and techniques may be involved in several disciplines while individual disciplines typically incor-

Table 1 Multi-skill, problem-focussed research dimensions

S	*Substantive Knowledge* Elements Needed	
	—'Frontier professional' Understanding Required	S_i
	—'Journeyman, textbook' Understanding Sufficient	s_i
T	*Technique* Needed	
	—'Expert' Level Needed	T_i
	—'Technician' Level Sufficient	t_i
R	*Range*	
	where subscripts to S and T:	
	i = A, B, C implies these routinely reside within an established research area:	R_1
	i = D, E, F (as well as A, B, or C) implies these draw from research areas other than A, B, C, but within the same broad intellectual area	R_2
	i = X, Y, Z (as well as A, B, or C) implies these are associated with research areas notably different from A, B, C.	R_3
A	*Administrative Unit Complexity*	
	—Single unit	A_1
	—multiple, linked units (report to the same higher administrator)	A_2
	—multiple, dispersed units	A_3
P	*Personnel*	
	—Single individual	P_1
	—Quasi-Permanent Team (e.g., a lab)	P_2
	—Ad Hoc Project Team	P_3

porate a range of substantive areas and techniques.

For the purposes of our work, we also see a need to distinguish between high and low levels of expertise in substantive areas and techniques. A high level of expertise can be operationalized as 'state-of-the-art', that is able to make original contributions to develop the intellectual skill (e.g. that are publishable). The low level of expertise can be described as understanding and being able to use and communicate the basic features of the intellectual skill in question—the 'textbook' or technician level.

Table 1 presents a typology of research problem dimensions selectively chosen to emphasize the complex requirements we have related to IDR. We begin with the identification of the substantive areas, S, and techniques, T, involved in the project. The depth of knowledge required is denoted for each by capitalization for high and a small letter for low. In addition we have selected three basic variables from the collection of possibilities discussed by Rossini *et al.* (1981) and Birnbaum (1982).

The first variable is the range of the intellectual skills required for the problem (R). In our study of technology assessments, a form of policy analyses (Rossini *et al.*, 1981), we found projects that typically had an enormously broad range of S and T. Recently we completed a project that attempted to develop literature-based indicators of IDR (Chubin *et al.*, 1983). We found that the involvement of people with truly disparate backgrounds in the basic and applied research areas we were studying was extremely rare. We wonder if we may have been deluding ourselves in that a number of us studying interdisciplinary processes are ourselves involved in particularly heterogeneous policy studies. We observed in the indicators project that people with seemingly quite different backgrounds working together on a study may reflect a closely shared interest in the particular topic, obviating intellectual distance. As an example, we studied a sample of groupings used by the Institute for Scientific Information. One that offered promise of interdisciplinarity was operations research. Surely, it involves engineers, management scientists, and mathematicians. This category appears both in the Science Citation Index and the Social Science Citation Index with an overlap of only 10% of the journals. Yet, on inspection, the shared research focus is quite tight. Most citations are to literature classified in the same operations research groupings.

The range of skills required on a project is variable, but typically narrow. We have partitioned R into three categories: (1) All skills are found in a single established research

Table 2 Selected multi-skill, problem-focussed research project configuration (STRAP)

1.	$S_A T_D$	$R_2 A_1 P_1$	(substantive A specialist learns and applies technique D from another area)
		$R_2 A_N P_{2/3}$	(collaboration)
2.	$s_A T_X$	$R_3 A_1 P_1$	(technique X expert working far afield)
3.	$S_A T_X$	$R_3 A_1 P_1$	(technique X expert learns the A area or substantive A specialist learns the X technique)
		$R_3 A_N P_{2/3}$	(collaboration)
4.	$S_A s_D S_E t_A t_D t_E T_X t_Y$	$R_3 A_1 P_1$	(ALP's psychology dissertation)
		$R_3 A_N P_{2/3}$	(collaboration)
5.	$S_A S_B S_D S_E S_X S_Y T_A t_B T_D t_E T_X t_Y$	$R_3 A_{2/3} P_3$	(very complex problem requiring collaboration across disparate skills and multiple organizations)
6.	$S_A S_B S_D S_X T_X$	$R_{2/3} A_2 P_2$	(central technique facility serves multiple substantive areas)

Note: See Table 1 for STRAP definitions. Subscript 'N' = 1 or 2 or 3.

area: (2) Skills are only found in more than one research area, but represent the same broad intellectual area (e.g. physical sciences, life sciences, or social sciences); (3) Skills are from diverse research areas that cross the boundaries of broad intellectual areas (e.g. engineering and law, or, possibly, humanistic and behavioural psychology).

To make this conept useful, we must operationalize established research area. Established research area refers to a community of researchers who publish in the same journals, share their work readily, possibly through exchanging preprints, go to the same meetings, and are generally in close intellectual contact with one another. Clearly the placement of S and T in areas changes over time. Thus we refer only to the situation at the time of the project.

The final two variables are administrative unit complexity, A, and personnel, P. These variables are relatively clear and operational as they stand.

A research project can be described by the STRAP variables with an enumeration of S&T and values for R, A, & P. As the subscripts of the RAP variables increase, the project described moves from relative simplicity to relative complexity.

Table 2 presents a sampling of research project configurations to illustrate application of the multi-skill, problem-focussed STRAP framework. We assume that 'research' implies expert level skill in at least one substantive area or technique. Here we only consider research that draws from more than one research area. This table and the following discussion are for flavouring only. The types listed in no way exhaust the interesting cases.

The first form listed in Table 2 presents an individual bringing a research technique from outside the research area to bear on it. The alternative collaborative form would involve two persons, one with the substantive knowledge, the other with the technical skill, working together. One could empirically study which arrangement is more effective under given conditions. Different traditions seem to hold in different areas of science. The neurosciences, for instance, lean toward the individual model; policy research toward the collaborative model.

The second illustration posits a technique expert applying his or her skills to problems demanding only journeyman knowledge of the substantive matters. In contrast, illustration 3 calls for expert understanding in an area quite different from the traditional technique application domain. Again, one can contrast individual versus collaborative strategies. 'P2' long term collaborative arrangements might be illustrated by the hiring of an electrical engineer by a neuroscience lab.

Illustration 4 depicts the dissertation research of one of us (ALP). The primary substantive area (S_A) was animal model memory processing. This was backed by working familiarity (s_D) with a particular one-trial learning model in the chick and some understanding of chick electrophysiology. To study the effects of non-hydrogen-bonding anaesthetics on memory (S_E) required several techniques. Statistical analysis (t_A) was needed. Technician level skill in constructing microelectrodes and surgical implantation was required along with EEG equipment operation and interpretation (t_D). Devising computer logic circuits for experimental control (t_E) was a third. The only technique considered to be at the expert level involved a xenon recovery system (T_X). Lastly, we could point to the 'plumbing' skills in hyperbaric gas chamber operations with changing gas mixtures (t_Y). This particular research illustrates the possibility of an individual conducting multi-skill research. Collaboration would be an alternative, though one discouraged by academic tradition for dissertations. It also illustrates the pitfalls in classification in terms of interdisciplinarity. One could argue that this entailed real interdisciplinary integration of electrical and chemical engineering, psychology, anatomy, and physiology. But in the eyes of those involved, this was research fitting unremarkably within the memory research area. It yielded a psychology Ph.D. with no concerns about disciplinary purity. Interestingly, the only technique flagged as requiring state-of-the-art expertise drew at most on a B.Sc. level training in chemical engineering. Advanced degrees seem a questionable index of the skills brought to bear in a problem-focussed study.

The fifth illustration from Table 2 represents a generic, complex problem requiring collaboration, most probably of different organizational units. The degree of integration of the research components would be a prime concern because of the broad range of skills involved. Because of this range of expertise required, the use of integration mechanisms such as common group learning (wherein all team members become 'expert' in all aspects of the study) or integration by the project leader would appear inadvisable. Instead, one might consider use of a common model as an integrating device, or pairwise negotiation among specific team members where their expertise intersects (Rossini and Porter, 1979).

The final illustration suggests innovative arrangements to take advantage of particular skill availabilities in cost-effective ways. Here, a central technique facility serves a cluster of substantive research interests which may or may not be interdependent. Even if the substantive experts work on independent projects, they may interact in informal ways and enrich student training by their mutual presence. One can imagine many other arrangements that facilitate multi-skill interchanges.

GENERATION OF HYPOTHESES

Table 3 presents ten selected hypotheses deriving from the multiple skills framework. These hypotheses are illustrative in nature. We hope to use this scheme shortly to generate, and adduce evidence for, specific hypotheses in a current study of 40 projects funded by the U.S. National Science Foundation.

The first hypothesis relates 'type' of project (basic research, applied research, development) to the range of S&T involved. Thus these 'types' differ in range (R) of S&T. We hope our present review of 40 projects will speak to this empirically.

The second hypothesis postulates an inherent link between skill composition of a study and interpersonal and organizational factors. This relates to empirical research on interdisciplinarity (cf. Birnbaum, 1982. Rossini *et al.*, 1981).

The third hypothesis suggests organizational constraints imposed may hinder successful solution of complex problems. For instance, academic institutions may make collaboration unattractive by emphasizing individual contributions to a discipline for professional advancement or by resistance to cross-unit sharing of research funding. Funding agencies may adopt a single investigator model out of tradition or to distribute limited support more widely, making collaboration hard to support.

Hypothesis 4 differentiates substantive

Table 3 Selected hypotheses concerning multi-skill, problem-focussed research

1. Basic research projects will rarely be R_3 while policy research will be R_3 relatively more often.
2. As project skill requirements increase in complexity, interpersonal and organizational dimensions become more important determinants of project success.
3. Organizational constraints on collaboration may impede solution of complex research problems.
4. Integration of substantive knowledge is more often critical to problem solution than is integration of the contributing techniques.
5. It is easier to solve a development problem by partitioning it into discrete subproblems than a problem in basic research.
6. Careers of individual researchers can be tracked with respect to their acquisition of skills, collaborations, and institutional mobility. Organizational constraints may be suppressing optimal individual development patterns.
7. Support for acquisition of techniques not routinely found in researchers' own areas could expedite research productivity.
8. Complex problem research supplants simple research when individuals invest in acquiring broad skill complexes or commit to long term team research.
9. Permanent or quasi-permanent research teams will be more productive than ad hoc teams.
10. As A and P increase, leadership becomes more critical to success.

knowledge from technique knowledge. Integration within a project is more apt to involve substantive specialists to a critical degree.

Hypothesis 5 also addresses integration, as well as the type (see above) of research, suggesting that integration is more critical in basic research problems than in development ones.

Hypotheses 6–8 concern the professional development of individuals and its bearing on research productivity. Hypothesis 6 simply asserts that organizational constraints can lead to less than optimal career patterns of knowledge gathering and collaboration. Hypothesis 7 follows by suggesting increased productivity through special attention to individuals acquiring techniques normally not found in their substantive specialities. Sabbaticals and designated support programs for the scientist to learn a new technique may prove effective. Hypothesis 8 asserts that individuals who become involved with complex problem-focussed research are unlikely to return to simpler, disciplinary research.

Hypothesis 9 builds from the premises of the previous hypotheses. It offers strong implications for the management of multi-skill, problem-focussed research.

The final hypothesis suggests an important need for effective research leadership as problems become more complex.

CONCLUDING DISCUSSION

We believe that the STRAP framework with its emphasis on the problem provides more promise than the former work, ours included, focussed on the interaction among disciplines. The multi-skill emphasis directs attention to the project level and to more explicit 'ingredients' of successful research. It opens a broader range of personnel configurations to be considered in the management of such research, in particular, the single investigator model is no longer disallowed. By de-emphasizing disciplinarity, a more universal set of intellectual and organizational factors can more easily be accommodated. For one, this should make our STRAP framework more relevant to industrial and governmental research. Much of the institutional influence on the conduct of complex research has been implicitly stamped with the disciplinary (academic departmental) label. The organizational component of this is absent in most non-academic settings, and the intellectual implications are less clear as well.

The framework can be used to form generic descriptors of research projects. The variables can be used to describe many facets of their dynamics as well. The intellectual and organizational range of projects of interest is great. Many features proper to individual projects will have to be considered when the analysis descends to that level to adequately account for the dynamics and outcomes of individual researches.

Underlying the development of STRAP is our realization that many intellectual areas impinge on our understanding of multi-skill, problem-focussed research, including R&D management, research on interdisciplinary research processes, the study of complex problem solving, and the sociology of knowledge and of scientific institutions. If STRAP can serve as a vehicle to construct a conceptual synthesis from operational elements of these traditions, then it will be most helpful. In our current study of NSF projects, we are trying to determine its utility as a framework and guide. We invite others to join us in exploring the utility of STRAP.

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REFERENCES

Birnbaum, P. H. (1982). 'The organization and management of interdisciplinary research—a progress report'. *Journal of the Society of Research Administrators*, 13, 11–23.

Chubin, D. E. (1983). 'Beyond Invisible Colleges: A Bibliographic Essay', pp. 3–63 in D. E. Chubin, *Sociology of Sciences: An Annotated Bibliography on Invisible Colleges, 1972–1981*, New York: Garland.

Chubin, D. E., Porter, A. L., Rossini, F. A. and Connolly, T. (1983). 'Indicators of Interdisciplinary Research', Report to the National Science Foundation, Division of Science Resources Studies, Grant No. SRS-810566, Atlanta: Georgia Institute of Technology.

Darden, L. and Maull, N. (1977). 'Interfield theories', *Philosophy of Science*, 44, 43–64.

Kuhn, T. S. (1970). *The Structure of Scientific Revolutions*, Second Edition, Chicago: University of Chicago Press.

Mar, B. W., Newell, W. T. and Saxberg, B. O. (1983). Phone discussion about current research in industrial laboratories, University of Washington.

Meeth, L. Richard (1978). 'Interdisciplinary studies: A matter of definition', *Change*, 7, August: 10.

Nilles, J. M. (1975). 'Interdisciplinary research management in the university environment', *Journal of the Society of Research Administrators*, 6, Spring: 9–15.

Petrie, H. D. (1976). 'Do you see what I see? The epistemology of interdisciplinary inquiry', *Journal of Aesthetic Education*, 10, 9–15.

Porter, A. L. (1983). 'Interdisciplinary Research: Current Experience in Policy and Performance', *Interdisciplinary Science Reviews*, Vol. 8, 158–167.

Rossini, F. A. (1979). 'Technology Assessment: A New Type of Science?' in P. Durbin, (ed.), *Research in Philosophy and Technology*, Volume II, Greenwich, CT: JAI Press, 341–355.

Rossini, F. A. and Porter, A. L. (1979). 'Frameworks for integrating interdisciplinary research', *Research Policy*, 8, 70–79.

Rossini, F. A., Porter, A. L., Kelly, P. and Chubin, D. E. (1981). 'Interdisciplinary Integration within Technology Assessments', *Knowledge*, Vol. 2, 503–528.

Rossini, F. A., Porter, A. L., Chubin, D. E. and Connolly, T. (1984). 'Crossdisciplinarity in the Biomedical Sciences: A Preliminary Analysis of Anatomy', in *Proceedings of the Second International Conference on Interdisciplinary Research*, A. Pearson *et al.*, Eds., John Wiley.

Taylor, James B. (1975). 'Building an interdisciplinary team', In S. R. Arnstein and A. N. Christakis (Eds.), Perspectives on Technology Assessment, Jerusalem: Science and Technology Publishers, 45–60.

APPENDIX B

INTERDISCIPLINARY RESEARCH PROJECT REVIEW STUDY

Project: ______________________________ (No. ______)

Principal Investigator: ______________________________

Organization: ______________________________

Please review and correct our answers to questions 1-7.

1. Organization TYPE (1= academic department; 2= academic, ad hoc center; 3= academic permanent center; 4= non-academic, organizationally departmentalized, large; 5= non-academic, project or matrix structure, large; 6= non-academic, fluid structure, small; 7= other--please describe) ____

2. Is this research ROUTINE for the performing organization? (1= typical, 'old hat' work; 2= intermediate; 3= first time, 'novel' work) ____

3. Project DURATION: actual calendar months ____

4. STAGE of the research (1= no directly related prior projects; 2= prior work, not NSF-supported; 3= NSF continuation support) ____

5. TYPE of research (1= basic; 2= applied; 3= policy) ____

6. This pertains to the chart that appears below. We have tried to identify the SUBSTANTIVE AREAS of expertise and the TECHNIQUES required to perform this research. Could you please correct our impressions listed in the first column of the chart.

   In the second column we have interpreted the degree of expertise in each needed to accomplish the research. Could you please correct this where "1" implies routine familiarity or technician capability and "2" implies outstanding, "frontier" of knowledge expertise?

   Then, please review the first row of the chart where we have listed the major project participants based on our reading of the proposal. Please correct this by noting who actually worked to a major extent.

   In the second row, please correct our estimate of the full time equivalent (FTE) months worked on the project. In the third row, please correct our understanding of the organizational unit relationships to the P.I.

   Lastly, could you please correct our ootions of who provided the substantive expertise and techniques by placing an "X" in the appropriate intersection cells (between a given S or T and the individual)?

		Individuals Contributing Significantly to the Project							
Name		___	___	___	___	___	___	___	___
FTE (full time equivalent) Months		___	___	___	___	___	___	___	___
Organizational Unit (1= same unit as P.I.; 2= different unit within the organization; 3= from outside the organization)		___	___	___	___	___	___	___	___
Substantive Areas (S) and Techniques (T) Required to accomplish the research	Level of Expertise Required (1= journeyman; 2= expert)								
___	___	___	___	___	___	___	___	___	___
___	___	___	___	___	___	___	___	___	___
___	___	___	___	___	___	___	___	___	___
___	___	___	___	___	___	___	___	___	___
___	___	___	___	___	___	___	___	___	___
___	___	___	___	___	___	___	___	___	___
___	___	___	___	___	___	___	___	___	___
___	___	___	___	___	___	___	___	___	___
___	___	___	___	___	___	___	___	___	___
___	___	___	___	___	___	___	___	___	___

7. Who of the project team had collaborated on prior research?

Please answer questions 8-9 and prepare answers to questions 10-16. We will discuss these questions in our phone conversation.

8. Please list the names of the project's core team members (i.e. those who made major contributions to the project as a whole over its duration).

9. Please draw a map below to indicate the communication linkages among the core team members. Use ——— to show heavy interaction and ----- for moderate interaction.

10. In what sense, if any, do you see this project as interdisciplinary?

11. Did your organization provide mechanisms to facilitate the research collaboration, or, conversely, impose any barriers to it?

12. Did you observe any intellectual barriers among team members (if you had a team) impeding communication? Any differences in approaches to securing knowledge/solving problems among them?

13. We are interested in whether you used any particular approach to integrate different parts of the research. Four approaches that have been described are (A) project leader personally takes all the component contributions and integrates them into one coherent piece; (B) integration takes place through a series of person-to-person interchanges among participants at the intersections of their expertise; (C) contributions feed into a model that provides a common basis; (D) all pieces are fully digested by each team member, sometimes even rewriting each other's work, so that the project is fully the property of the team. Do any of these describe your project, or does any other strategy pertain?

14. Did you revise the problem during the course of the project? Did you iterate solutions?

15. In what notable ways did NSF personnel facilitate the project's funding or conduct?

16. Could you identify for us the "products" of this research (such as articles, books, patents, reports, theses)?

THANK YOU!

APPENDIX C

Listing of Variables Contained in the Main Projects File

```
FILE NAME       IDR
INPUT MEDIUM    DISK
VARIABLE LIST   V1 TO V59
N OF CASES      UNKNOWN
VAR LABELS      V1 PI
                V2 OLD NUMBER
                V3 NEW NUMBER
                V4 NSF PROGRAM
                V5 ORGANIZATION TYPE
                V6 PROJECT ROUTINE FOR ORGANIZATION
                V7 PROJECT DURATION -- TOTAL MONTHS
                V8 STAGE OF RESEARCH
                V9 TYPE OF RESEARCH
                V10 SUBSTANTIVE AREAS, FRONTIER LEVEL
                  *** FOR V10 TO V13, THIS IS THE NUMBER NOTED
                V11 SUBSTANTIVE AREAS, JOURNEYMAN LEVEL
                V12 TECHNIQUES, EXPERT LEVEL
                V13 TECHNIQUES, TECHNICIAN LEVEL
                V14 TEAM SIZE
                  *** FOR V14 AND V15 COUNT GRA'S IF PHD DISS TYPE INVOLVEMENT IN
                      PROJECT, USUALLY NOT IF LOW LEVEL MS SIDE EMPLOYMENT
                      COUNT TECHNICIANS IF SIGNIFICANT CONTRIBUTION TO NOTED S&T'S
                V15 CORE TEAM SIZE
                V16 PERCENT TEAM FROM RELATED UNITS (CODE 2'S/V14)
                  *** COULD RECODE TO  1=SINGLE UNIT, 2=MULTIPLE UNITS
                      UNDER SAME HIGHER ADMINISTRATOR, 3=CROSS-INSTITUTIONAL,
                      BUT THIS CONTINUOUS SCALING OFFERS MORE PROMISE
                V17 PERCENT TEAM FROM UNRELATED UNITS (CODE 3'S/V14)
                V18 PERSONNEL CONFIGURATION
                V19 FTE TEAM TOTAL
                  *** V19 = TOTAL FTE MONTHS FOR THE INDICATED DURATION PROJECT,
                      V20 THRU V25 GIVE PERCENTS
                V20 FTE PI PERCENT
                V21 FTE CORE TEAM PERCENT
                V22 S&T COVERAGE PI
                V23 S&T LEVEL 2 COVERAGE PI
                V24 S&T DENSITY CORE TEAM
                V25 S&T DENSITY TEAM
                V26 PRIOR EXPERIENCE AS TEAM
                V27 COMMUNICATION DENSITY (CORE TEAM)
                  *** WEIGHTS SOLID LINES AS 1, DASHED LINES AS 1/2,
                      DIVIDES BY N(N-1)/2
                V28 COMMUNICATION MAP FORM
                V29 IDR IN VIEW OF PI
                V30 ORGANIZATION SUPPORT
                V31 INTELLECTUAL BARRIERS
                V32 DIFFERENCES IN APPROACH
                V33 APPROACH TO INTEGRATION
                V34 PROBLEM REVISED
                V35 SOLUTION ITERATED
                V36 NSF FACILITATE FUNDING
                V37 NSF TECH INTERACTION POST-FUNDING
                V38 BOOKS
```

```
  *** V38 THRU V44 GIVE COUNTS ON EACH TYPE OF PRODUCT
V39 ARTICLES
V40 PRESENTED PAPERS
V41 PATENTS
V42 THESES
V43 REPORTS
V44 OTHER
V45 JUDGMENT ON HOW PRODUCTIVE PROJECT WAS
V46 OUR PROD INTEGRATION JUDGMENT
V47 ADVISORY COMMITTEE
V48 OUR JUDGMENT IF PROF REWARD
V49 PEER REVIEW RATING
V50 PI DISCIPLINE
V51 PI GRAND CATEGORY
V52 N DISCRETE DISCIPLINES ON CORE TEAM
  *** NOTE FOR V52 AND V53 THIS IS A TALLY OF
      THE NUMBER OF DIFFERENT DISCIPLINES REPRESENTED
      FOR V54 THE PERCENT IS PERSONNEL NOT DIFF DISC
V53 N DISCRETE DISCIPLINES ON TEAM
V54 PERCENT PERSONNEL OUTSIDE PI GRAND CTGY
V55 ISI CATEGORIES SPANNED BY PRIOR PUBS
V56 ELIZABETH JUDGMENT ST INTERACTION RQD
V57 ELIZABETH JUDGMENT HOW IDR
V58 ELIZABETH JUDGMENT PROGNOSIS
V59 RANGE OF SKILLS (S & T)
  *** NOTE THAT THIS VARIABLE IS OUT OF LOGICAL ORDER
V60 PROJECT STATUS
V61 PERCENT TEAM BOTH PROPOSAL & ACTUAL
```

comment — The following variables are computed from the above.

```
V62 Sum of V16 + V17 (% team from outside the PI's unit)
V62R recodes V62 so that greater or equal 40% = 1; less = 0
V63 Sum of V10 + V11 + V12 + V13 (sum of all S's + T's)
V64 Weighted sum of research products = 3*V38 + V39 + V40 +
    3*V41 + V42 + V43 + V44
    This weights books and patents 3; all others 1.)
V65 Interdisciplinarity factor (based on factor analyses) =
    .21 V29'  + .26 V53'  + .36 V54'  + .15 V57'  + .19 V59'
    (where V' represents that variable standardized)
V66 Sum of V10 + V11 (All S's)
V67 Sum of V12 + V13 (All T's)
V68 Sum of V10 + V12 (Sum of expert level S's + T's)
V5R recodes V5 categories 2 thru 7 together to yield
    academic department or other.
V6R recodes V6 categories 2 and 3 together.
V18R recodes V18 category 2 with category 1.
```

Subfiles — Cases 1 thru 20 = ALP; cases 21 thru 40 = FAR.

VALUE LABELS

```
V4   (1) GEOSCIENCES  (2) NEUROBIOLOGY  (3) ARCHEOLOGY
     (4) EARTHQUAKE  (5) SCI & TECH HANDICAP
V5   (1) ACADEMIC DEPT (2) ACAD AD HOC CTR (3) ACAD PERMANENT CTR
     (4)NON-AC ORG DPTMNTLZD (5)NON-AC LG PROJ/MTRX
     (6)NON-AC SM FLUID  ,
     (7) OTHER
V6   (1) TYPICAL WORK  (2) INTERMEDIATE  (3) NOVEL WORK
V8   (1)NO DIRECTLY PRIOR  (2)PRIOR WORK, NOT NSF
     (3)NSF CONTINUATION
V9   (1) BASIC  (2) APPLIED  (3) POLICY
```

V13 (1)SINGLE RESEARCHER (2)LAB--QUASI-PERM TEAM
(3)AD HOC PROJECT TEAM
V26 (1)NO PRIOR EXP TOGETH (2)SUBUNITS PRIOR
(3)YES PRIOR AS TEAM
V23 (1)HUB & SPOKES (2)INTERMEDIATE (3)ALL CHANNEL
V29 (0) NO (1) YES--NARROWLY (2) YES
V30 (1) BARRIERS IMPOSED (2)NEUTRAL (3)FACILITATED
V31 (0) NO (1) MINOR (2) MAJOR
V32 (0) NO (1) MINOR (2) MAJOR
V33 (1) BY LEADER (2)SERIES PERSON-PERSON
(3)MODEL (4)COMMON GROUP LEARN (5)MULTIPLE
(6)OTHER
V34 (0) NO (1) MINOR (2) MAJOR
V35 (0) NO (1) YES
V36 (0)NO OR NEUTRAL (1)MINOR (2)MAJOR
V37 (0) NO (1) MINOR (2) MAJOR
V45 (0) NONE (1) MINIMAL
(2) SUBSTANTIAL (3)HI QUAN & QUAL
V46 (0) NONE (1) MINOR (2) MAJOR
V47 (0) NO (1) YES
V48 (0) NIL (1) MINOR (2) MAJOR
V49 (1) EXCELLENT (2)VERY GOOD (3) GOOD
(4) FAIR (5) POOR
V50 (420)CIVIL ENGR
(421)STRUCTUR ENGR
(430)CHEM ENGR
(435)ELEC ENGR
(470)MECH ENGR
(480)BIOMEDIC ENGR
(545)ANATOMY
(540)BIOCHEM
(542)BIOPHYSICS
(538)MEDICINE
(537)PSYCHIAT
(539)NEUROLOGY
(536)PHARMACOL
(579)CELL BIOLOGY
(572)MOLECULR BIOLOGY
(566)ANIMAL PHYSIOL
(580)NEUROSCI
(584)NEUROBIO
(298)CHEMISTR
(095)COMPUTER SCIENCE
(396)EARTH SCIENCES
(399)GEOCHEM
(397)SOIL CHEM
(098)MATH
(111)PHSYICS
(729)STATIST
(112)GENERAL PHYS SCI
(399)METEOROL
(862)BUS ADM
(938)EDUC
(886)LAW
(891)LIBR & INFO SCI
(887)SOC WORK
(665)SPEECH & HEARING
(883)BROADCST
(884)AUDIOLOG
(688)COMMUNIC SCI
(889)LINGUIST
(770)URBAN & RGL PLAN
(775)DISASTER SPEC
(696)OTHER PROF FLDS

```
                (900)ADMINISTRATOR
                (700)ANTHROP
                (720)ECON
                (740)GEOG
                (750)POLI SCI   PUB ADM
                (601)PSYCH
                (760)SOCIOL
                (799)GENERAL  SOC SCI
            V51 (1)PHYS SCI  MATH  (2)LIFE SCI  (3)ENGINEER
                (4)SOC SCI/   PSYCH
                (5)PROF FLD
                (6)ARTS &   HUMANITIES
            V56 (1)ESSENTIALLY INDEP  (2) LITTLE (3)MEDIUM
                (4)HEAVY (5)V HEAVY/ NEED INTEGR
            V57 (1)NOT (2) LITTLE (3)MEDIUM
                (4)HEAVILY )V HVLY/  V BROAD
            V58 (1) POOR  (2) FAIR  (3) MIDDLE (4) GOOD  (5)EXCELLNT
            V59 (1)S&T WITHIN RES AREA  (2)S&T IN GRND CTGY
                (3)S&T SPAN GRND CTGIES
            V60 (1)STILL UNDERWAY  (2)RESEARCH COMPLETE, BUT STILL
                PUBLISHING  (3)RESEARCH PRODUCTION COMPLETE
            V61 % OF TEAM NAMED EITHER IN PROPOSAL OR AS ACTUAL
                SIGNIFICANT CONTRIBUTORS THAT ARE NAMED IN BOTH


INPUT FORMAT    FIXED (A10,A3,F2.0,3F1.0,F2.0,2F1.0,
                6F2.0,2F2.0,F1.0,7F2.0,F1.0,F2.0,
                10F1.0,7F2.0,4F1.0,F2.1,F3.0,F1.0,4F2.0,5F1.0,F2.0)
```

comment — Other variables are derived for specific analyses as needed and described therein. For instance, various interactions are examined through a series of regressions.

0

APPENDIX D

Listing of Variables Contained in the Peer Review File

```
INPUT MEDIUM    DISK
VARIABLE LIST   PROPOSAL,PROGRAM,PIDISC,PIDEPT,REVNUMBR,REVDISC,REVDEPT,
                DISCMTCH,RATING

comment         PROPOSAL gives an assigned number to each of the 40 proposals;
                PROGRAM indicates which of the 5 NSF programs; see VALUES LIST .
                PIDISC indicates discipline of the proposal principal investigtr.
                PIDEPT shows the type of organizational affiliation.
                REVNUMBR assigns a number to each reviewer.
                REVDISC indicates discipline; see VALUES LIST below.
                REVDEPT is comparable to PIDEPT.
                DISCMTCH indicates similiarity of  PI and REVIEWER disciplines.
                RATING is the numerical rating given the proposal.

N OF CASES      UNKNOWN
VALUE LABELS
                PIDEPT,REVDEPT (1)AC DEPT
                (2)AC INTRM
                (3)AC CTR
                (4)QP FUNDR
                (5)GVT FUND
                (6)LG CNSLT
                (7)SM CNSLT
                (8)CMRCL FM
                (9)QP USER
                (10)GVT USER/
comment          AC is academic; QP is quasi-private;
                CMRCL FM is commercial firm; USER is an organization
                usually thought of as a user of research.

                PROGRAM (1)GEOSCI  (2)NEUROBIOLOGY (3)ARCHEOL
                (4)ERTHQUAK (5)STAH
comment         STAH is science and technology to aid the handicapped.

                /DISCMTCH (1)SAME (2)SIMILAR (3)DIFFRNT/

                PIDISC,REVDISC (420)CIVIL ENGR
                     (421)STRUCTUR ENGR
                     (430)CHEM ENGR
                     (435)ELEC ENGR
                     (470)MECH ENGR
                     (480)BIOMEDIC ENGR
                     (545)ANATOMY
                     (540)BIOCHEM
                     (542)BIOPHYSICS
                     (538)MEDICINE
                     (537)PSYCHIAT
                     (539)NEUROLOGY
                     (536)PHARMACOL
                     (579)CELL BIOLOGY
                     (572)MOLECULR  BIOLOGY
```

```
                    (566)ANIMAL    PHYSIOL
                    (580)NEUROSCI
                    (584)NEUROBIO
                    (298)CHEMISTR
                    (095)COMPUTER  SCIENCE
                    (398)EARTH     SCIENCES
                    (399)GEOCHEM
                    (397)SOIL      CHEM
                    (098)MATH
                    (111)PHSYICS
                    (729)STATIST
                    (112)GENERAL  PHYS SCI
                    (882)BUS ADM
                    (938)EDUC
                    (886)LAW
                    (891)LIBR &  INFO SCI
                    (887)SOC WORK
                    (855)SPEECH & HEARING
                    (883)BROADCST
                    (884)AUDIOLOG
                    (888)COMMUNIC  SCI
                    (889)LINGUIST
                    (770)URBAN & RGL PLAN
                    (775)DISASTER SPEC
                    (898)OTHER    PROF FLDS
                    (900)ADMINISTRATOR
                    (700)ANTHROP
                    (720)ECON
                    (740)GEOG
                    (750)POLI SCI   PUB ADM
                    (601)PSYCH
                    (760)SOCIOL
                    (799)GENERAL  SOC SCI

INPUT FORMAT    FIXED (F2.0,F1.0,F3.0,F2.0,2F3.0,F2.0,F1.0,F2.1)
MISSING VALUES  REVDISC TO RATING (BLANK)
PRINT FORMATS   RATING (2)


IF              (PROPOSAL NE 0)NUMBRE = 1
IF              (REVDISC GE 400 AND LE 499) REVCTGY = 3
IF              (REVDISC GE 500 AND LE 599) REVCTGY = 2
IF              (REVDISC NE 729 AND NE 770 AND NE 775 AND GE 601
                AND LE 799) REVCTGY = 4
IF              (REVDISC LE 399 OR EQ 729) REVCTGY = 1
IF              (REVDISC EQ 770 OR EQ 775 OR GE 850) REVCTGY = 5
IF              (PIDISC GE 400 AND LE 499)PICTGY = 3
IF              (PIDISC GE 500 AND LE 599) PICTGY = 2
IF              (PIDISC NE 729 AND NE 770 AND NE 775 AND GE 601
                AND LE 799)PICTGY = 4
IF              (PIDISC LE 399 OR EQ 729) PICTGY = 1
IF              (PIDISC EQ 770 OR EQ 775 OR GE 850)PICTGY = 5
ASSIGN MISSING  PICTGY (BLANK)
ASSIGN MISSING  REVCTGY(BLANK)
IF              (PICTGY EQ REVCTGY)CTGYMTCH = 1
IF              (PICTGY NE REVCTGY)CTGYMTCH = 0
ASSIGN MISSING  CTGYMTCH (BLANK)
VALUE LABELS    CTGYMTCH (0)DIFFRENT (1)SAME
comment         CTGYMTCH provides an alternative to DISCMTCH in
                assessing how similar PI and REVIEWER disciplines are.


VALUE LABELS    PICTGY,REVCTGY (1)PHYS SCI AND MATH (2)LIFE SCI (3)ENGINEER
```

```
                (4)SOC SCI AND PSYCH (5)PROFESNL FIELDS
comment         PICTGY and REVCTGY cluster backgrounds into grand
                disciplinary categories as per National Research Council codes.

IF              (PIDEPT LE 3) PI = 1
IF              (PIDEPT GE 8) PI = 3
IF              (PIDEPT GT 3 AND LT 8) PI = 2
IF              (REVDEPT LE 3) REV = 1
IF              (REVDEPT GE 8) REV = 3
IF              (REVDEPT GT 3 AND LT 8) REV = 2
VAR LABELS      PI  PI DEPARTMENTAL AFFILIATION AGGREGATED/
                REV REVIEWER DEPT AFFILIATION AGGREGATED/
VALUE LABELS    PI,REV (1) ACAD  (2)NONAC RS (3)USER

COMPUTE         DISCPROG = DISCMTCH * PROGRAM
ASSIGN MISSING  DISCPROG (BLANK)
COMPUTE         PIAC = PI
COMPUTE         REVAC = REV
RECODE          PIAC,REVAC (2,3 = 0)
COMMENT         PIAC AND REVAC INDICATE WHETHER ACADEMIC OR NOT

COMPUTE         PICTG = PICTGY
COMPUTE         REVCTG = REVCTGY
RECODE          PICTG,REVCTG (3 = 6) (4 = 3)
RECODE          PICTG,REVCTG (6 = 4)
COMMENT         PICTG AND REVCTG ARE REORDERED SLIGHTLY TO RUN
                FROM BASIC TO APPLIED

COMPUTE         REVDIS = REVDISC
COMPUTE         PIDIS = PIDISC
RECODE          PIDIS,REVDIS (430,435,470,298,098,111,700,
                720,740,750,601,760 = 1) (ELSE = 0)
COMMENT         PIDIS AND REVDIS ARE DISCIPLINE RECODED SUCH
                THAT 1 = 'TRADITIONAL' AND 0 = OTHER.

                CONSERV COMBINES THIS WITH WHETHER REV RESIDES IN ACADEMIA
IF              ((REVAC EQ 1) AND (REVDIS EQ 1)) CONSERV = 4
IF              ((REVAC EQ 1) AND (REVDIS EQ 0)) CONSERV = 3
IF              ((REVAC EQ 0) AND (REVDIS EQ 1)) CONSERV = 2
IF              ((REVAC EQ 0) AND (REVDIS EQ 0)) CONSERV = 1
ASSIGN MISSING  PIAC TO CONSERV (BLANK)
FINISH
```

FINAL REPORT
Volume 2

INTERDISCIPLINARY RESEARCH (PROBLEM-FOCUSSED, MULTI-SKILLED RESEARCH) – NATIONAL SCIENCE FOUNDATION EXPERIENCES

By
Alan L. Porter
Frederick A. Rossini
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Prepared for
NATIONAL SCIENCE FOUNDATION

March 1984

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF INDUSTRIAL & SYSTEMS ENGINEERING
ATLANTA, GEORGIA 30332

1984

INTERDISCIPLINARY RESEARCH (PROBLEM-FOCUSSED, MULTI-SKILLED RESEARCH) — NATIONAL SCIENCE FOUNDATION EXPERIENCES

Final Report to the National Science Foundation

Georgia Institute of Technology
March, 1984

by

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We gratefully acknowledge the support of the National Science Foundation, Office of Interdisciplinary Research, under Grant OIR-8209893. The views expressed are those of the authors and do not necessarily reflect those of NSF or the Georgia Institute of Technology. We thank Terry Connolly, our co-principal investigator who left his insights and guidance as he moved to the University of Arizona, and Elisabeth Kotzakidou, who served as graduate research assistant. We deeply thank the NSF Program Managers who helped us access projects and shared their knowledgable perspectives:

--James C. Aller, Science and Technology to Aid the Handicapped Program
--William A. Anderson, Earthquake Hazard Mitigation, Societal Response Research
--James H. Brown, Division of Behavioral and Neural Sciences
--Steven E. Kornguth, Neurobiology Program
--John A. Maccini, Environmental Geosciences Program
--Charles L. Redman, Anthropology (Archeology) Program
--Joseph L. Young, Memory and Cognitive Processes Program.

We are especially indebted to the 40 busy researchers who took time to review our characterization of their projects and to discuss that research with us.

For further information, contact Alan Porter by phone: (404) 894-2330, or mail: ISyE, Georgia Tech, Atlanta, GA 30332.

EXECUTIVE BRIEF

INTERDISCIPLINARY RESEARCH

Interdisciplinary Research (IDR) presents unique and substantial difficulties for researchers and research managers. Yet it is widely practiced because it often constitutes the most important scientific and engineering research, both in its potential for intellectual breakthroughs and for the solution of critical societal problems. IDR is often performed within organizational structures that are not oriented toward it. There are substantial incentives to understand how IDR works, from concept generation and review through the reseach process to the resulting products and their use, in order to improve its performance.

STUDY OBJECTIVES

The Office of Interdisciplinary Research of the National Science Foundation (NSF) is committed to understanding and facilitating IDR. It commissioned this study to:

(1) Identify the most important literature on IDR;
(2) Critically synthesize knowledge on IDR to guide research on IDR processes;
(3) Examine a number of projects supported by various NSF programs to gain additional insight into the factors that help and hinder IDR.

STUDY COMPONENTS

The study contains threeee components: bibliographic, conceptual, and empirical.

The literature review built on our experience in studying IDR and the process of preparing a book of readings. A computerized search and informal networking extended it so that Volume II of this report consists of a bibliographic overview and a selection of annotated items current through November, 1983.

As our literature synthesis and preliminary empirical work progressed, we became convinced that the usual approach to IDR as an interaction among scholarly disciplines was inadequate. As a consequence, we rethought the bases of our understanding of IDR. The result was the STRAP framework for describing the static properties of an IDR project. The key change is that "intellectual skill" replaces discipline as the primary intellectual unit of analysis. Organizational and personnel factors are also included. Hypotheses developed from this framework guided our empirical work.

The empirical work itself involved the study of 40 research projects from five NSF programs, involving basic, applied, and policy research. These five are Archeology, Neurobiology, Environmental Geosciences, Science and Technology to Aid the Handicapped, and Earthquake Hazard Mitigation-Societal Response. The sample was purposive, emphasizing IDR projects within accomodating programs. We interviewed the NSF program managers about IDR funding, project management, and evaluation. We then obtained the proposals and sanitized versions of the peer reviews. We abstracted information from each proposal, then mailed this to the principal investigator. Phone conversations clarified and augmented our interpretations. Volume I of this report consists of the analysis of the research process and peer review data in relation to the previously framed hypotheses.

CONCEPTUAL HIGHLIGHTS

Our project deals with IDR at the program and project levels. Research program development, whether within NSF or another formal research organization, or in an informal network of researchers, involves both intellectual and organizational factors. The intellectual factors are usually lumped under the category of disciplines. These factors interact with organizational factors, for example in the areas of research training and project management.

Discipline, which carries both intellectual and organizational connotations, especially in academe, has serious limitations as a primary unit of analysis for studying research processes. The problem is most obvious at the project level where successful IDR is most commonly viewed as the integration of various disciplinary components to form a single analysis. These limitations include the following:

* Intellectual and/or organizational differences may be more acute within a discipline than between disciplines. For example, humanistic and behavioral (clinical) psychologists are further apart than some experimental chemists and physicists;
* Some individual researchers do not fit neatly within a single disciplinary category;
* Research areas involving intellectual communities do not always map cleanly onto disciplines;
* IDR problems may be addressed by individuals as well as teams;
* The central role of discipline tends to narrow the focus on IDR to academic research, an ill-founded restriction.

The STRAP framework, which we developed during this project, offers a new perspective on IDR. Its driving premise is that there is a class of problems whose solution requires many intellectual skills. These skills may or may not relate closely to disciplines and may or may not be combined within a single individual. Skills are divided into substantive area expertise (S) and technique expertise (T). These skills may be exercised at either the expert or journeyman level.

The remaining STRAP variables are:

(1) Range (R)-the degree to which the substantive areas and techniques reside within established research areas;
(2) Administrative Unit Complexity (A)-the number and relationship of the organizational units involved in the conduct of the research;
(3) Personnel (P)-the number and relationship of the researchers involved in the project.

STRAP broadens the consideration of problem-focussed research to encompass non-academic organization and individually performed IDR. It suggests new strategies for training researchers and alternative ways of composing research teams.

EMPIRICAL RESULTS

Characteristics of the Projects Studied

These projects are viewed by 87% of their principal investigators (PIs) as interdisciplinary. Indeed this characterization is appropriate with an average of 6 intellectual skills identified per project and 60% of the projects involving skills from more than a single research area.

In the areas we studied, academic departments proved surprisingly open to drawing on research skills beyond traditional disciplinary domains to attack interesting problems. Researchers had high expectations of professional reward for IDR. However, such open departments seem to constitute only a fraction of academic units.

Findings Relating to the STRAP Framework

The PIs understood the concept of intellectual skills that were not simple images of disciplines. About 3 substantive areas and 3 techniques characterized the median project.

In the projects we studied it was typical for each researcher to possess a relatively small number of skills. Laboratory based projects had a greater skill overlap than did other projects.

Projects involving many substantive areas are more likely to be team research than those involving a comparable number of techniques. Individuals more readily master techniques than substantive areas.

As indicated in Table ES-1, applied, as contrasted with basic, research projects show a wider range of substantive areas and techniques, more participants from outside the PI's discipline, less likelihood of continuing sponsor support, and greater likelihood of ad hoc project team arrangements.

Policy research projects vary considerably among themselves, tending to be intermediate between basic and applied projects in skill mix and team permanence, but lowest in likelihood of continuing support.

Applied research projects have less skill overlap among participants than do basic or policy research projects.

Organizational barriers to the conduct of research were noted in only 5% of the projects.

Peer Review

Peer ratings tend to be more favorable for academic PIs (1.63) than for non-academic PIs (2.18; $\underline{t}$=4.29, $p < .0001$).

Peer ratings tend to be more favorable for proposals funded in basic research (1.51) than for those in applied and policy research [2.05; $\underline{t}$=4.55, $p < .001$]. The applied and policy projects are all in the Engineering Directorate of NSF.

Peer ratings tend to be less favorable for more interdisciplinary projects (rho=.23).

Peer reviewers from disciplines differing from the PI rate proposals less favorably (2.07) than do reviewers closely associated with the PI's discipline (1.73; $\underline{F}$=6.70, p=.01).

IDR Project Differences Across NSF Programs

As Table ES-2 indicates, the interdisciplinary characteristics of the projects differ across the five NSF programs, for instance:

* Archeology projects tend to involve the largest teams.
* Geoscience and Science and Technology to Aid the Handicapped (STAH) projects tend to ad hoc research teams; Neuroscience and Archeology projects lean toward more permanent teams.
* Professional reward for researchers is more questionable on applied and policy research projects.
* STAH projects involve the greatest percentage of participants from disciplines different from the PI.
* STAH and Archeology projects are the most interdisciplinary.

IDR in Academe

Some academic departments are "open" to IDR while others are "closed" to it. This counters the stereotype of disciplinary academic departments opposing IDR.

Cross-disciplinary training arrangements, as exemplified by British interdisciplinary and U.S. Neuroscience Ph.D. programs, offer potential for training researchers to practice IDR.

RECOMMENDATIONS

NSF has made progress in furthering appropriate interdisciplinary research. Further development is possible through selected activities in three areas:

(1) Carefully chosen research on IDR processes;
(2) Prods to academe;
(3) Changes in NSF practices.

We urge research on two facets of IDR. The STRAP framework offers real promise in broadening 'IDR' perspectives to problem-focussed research demanding of multiple skills. In particular, improved measures of intellectual skills, critical review of the other variables, and empirical testing of the link between research processes and products are needed. In addition, an empirical study of organizations "open" and "closed" to multiple-skilled research and their characteristics would help clarify the organizational role in facilitating/discouraging IDR. A detailed analysis of the differences between "open" and "closed" academic departments could be truly enlightening.

NSF and others can act to minimize organizational resistance to IDR from academe. Budgetary arrangements for sharing overhead among various participating academic units can be encouraged to reduce financial tensions. Professional career reviews of academics could incorporate reviewers from their areas of expertise, whether or not these lie inside the traditional boundaries of their academic discipline. Postdoctoral grants and appointments might require the transfer of new intellectual skills into the group where the postdoc will be working. Major equipment grants or purchases could require shared use, preferably by researchers from different units.

On the NSF front, the Foundation should take into consideration the extra work involved in encouraging, reviewing, and funding IDR proposals by its program managers. It should encourage mechanisms for multiple program funding of IDR projects, more than is presently done. NSF should consider an "IDR set aside" so that good research does not drop through the cracks between existing programs. Small businesses have largely untapped potential as performers of IDR. NSF should move to facilitate their participation in its programs.

As documented in this study, the peer review process of NSF presents special hurdles to IDR. Review by a disjoint set of experts in individual areas would seem to doom an IDR proposal to lower ratings than an equivalent disciplinary project, based on our observation of less favorable ratings by reviewers from different disciplines than the PI. Multiple panels only mean multiple jeopardy. NSF should instead seek reviewers who possess sufficient breadth and are committed to the proposed research area. Alternatively, it should adjust award mechanisms with the expectation of weaker ratings for IDR projects. Incorporating feedback into the review process (e.g. a delphi-like process in which reviewer comments are fed back to the PI and then all comments are circulated iteratively before final ratings are made) could limit the problems of reviewing IDR projects.

NSF was repeatedly credited with facilitating the development of IDR. Strengthening the mechanisms for proposal review and project oversight of IDR within the Foundation should serve to further lower the barriers to and reap the high payoffs from IDR.

TABLE OF CONTENTS

November 1983

INTERDISCIPLINARITY: HOW DO WE KNOW THEE? - A BIBLIOGRAPHIC ESSAY

Daryl E. Chubin, Alan L. Porter, and Frederick A. Rossini

This volume has sought to present a comprehensive introduction to interdisciplinarity as a subject, a process, and a mode of intellectual and social organization. From our opening essay advocating the so-called STRAP framework, through the excerpts collected and grouped thematically, we have captured the state of the art--or at least fashioned a retrospective on it.

The capstone of any introduction, however, should be a research agenda defined by the corpus of literature. This essay is an attempt to inventory that literature, quantitatively and qualitatively, to assist the reader in developing his/her own perspective on the diverse analyses and commentaries on the phenomenon "interdisciplinary research" (IDR).

A Bibliometric Profile

The literature on interdisciplinary research (IDR) is over 30 years old--if one cites its origin as a paper containing the word "interdisciplinary" in its title--beginning with a paper published in 1951 about the problems of collaboration between an anthropologist and a psychiatrist [35]. (Numbers appearing in [] refer to items included in the annotated bibliography that follows.)

A more quantitative glimpse at the literature we have identified and retrieved as IDR requires what is known as "bibliometrics" [exemplified here by items 111 and 123]. Bibliometric analysis characterizes trends in literature growth by publication type, source scatter, and usage. Given the dearth of systematic study of IDR as a literature [but see 20, 72, 105, 122,], we have some statistics to report, but an abundance of impressions to offer. (Recognize that our literature sample is not all-inclusive; it tends, for example, not to itemize chapters within books.) We invite the reader to sample the bibliography discreetly, pursuing what intrigues and ignoring the seemingly irrelevant. Because IDR encompasses a range of activity, and presumably motivation, a comparable range of utility to the reader is expected.

Figure 1 displays two curves. The broken line portrays a frequency distribution by year of the 134 items in the annotated bibliography; the solid line portrays the cumulative frequency distribution of those IDR items over the period from pre-1969 to 1982. What appears to be an irregular growth pattern is marked by a clear "take-off" in 1975. Thus, the literature divides into three segments or "eras": the first spans 1951-68 and features no more than a sprinkling of IDR, the second, "emergent" era, 1969-74, indicates a measurable flow averaging five items per year, and the third, take-off era, 1975-82 (the latter incomplete due to retrieval lag) signals a "leaping" step-function of IDR.

Another way of characterizing growth is through doubling times: how many years does it take for the literature to increase its total size by 100 percent? The following spurts can be noted. The 1969 total nearly equalled the sum of the 1951-68 items; the literature doubled between 1969-72; the 1975 output increased the size of the literature preceding that year by 37 percent; two years later there was another 30 percent increase; from 1973-77, the literature grew by 120 percent; and from 1978-82, 95 percent growth occurred. The overall doubling time, then, approximates 4.5 years--a brisk pace, but a small population nonetheless.

Still another method of calculating literature spurt is to summarize the proportion of IDR by era. The significant figure is the nearly three-quarters of the literature sample that was produced during the take-off era. More than half of this work, and 40 percent of the 134 items, was produced since 1979. This so-called recency effect suggests that specialists in IDR now exist [19] and that a portion of the literature is coalescing around a core of journals and practitioners [20]. Such observations, however, move away from bibliometric data to an analysis of publication and source content.

As shown in Table 1, journal articles dominate as the publication type for IDR. Slightly more than one-fourth of IDR appears in books, book chapters, and reports/unpublished papers combined. This domination of the serial literature prompts a tally of the journals publishing IDR.

As seen in Table 2, 36 of the 98 serial items are concentrated in only 10 journals--and 9 of these published no more than 4 articles/editorials each. Thus, the outlets for the remaining items in this category are 62 _different_ journals. In addition, the journals in Table 2 dispel suspicion that there is much, if any, of a core of IDR journals. We would characterize the set of 10 as management, policy, and multidisciplinary science, social science, and engineering in orientation. (We note with surprise the absence of the 7-year-old "flagship" journal, _Interdisciplinary Science Reviews_ [see 82].) In sum, dispersion is the norm.

An Analysis of Content

At this juncture, bibliometric analysis might profitably yield to a content analysis of titles and annotations. The dimensions of interest, in the case of the former, are keywords. Table 3 lists the most frequently-appearing keywords among the 134 items. (More than one of these keywords, of course, could be found in a single title.) Again, diversity reigns.

A major concern, it would seem, has been the conduct of IDR in academic settings, and particularly, in campus-wide research centers or ORUs ("organized research units") [4, 27, 36, 59, 66, 106, 118,]. Some of these titles link other popular keywords in Table 3 to the academic setting. Some examples include "Assessment of Alternative Management Forms in Academic Interdisciplinary Research Projects" (italics ours)[21], "Interdisciplinary Research Management in the University Environment" [83], "Managing Multidisciplinarity: Building and Bridging Epistemologies in Educational R&D" [106], and "Trends in the Organization of Academic Research: The Role of ORUs and Full Time Researchers" [118].

"Management," "teamwork," and "organization" also signal other, nonacademic IDR directions. To wit: Management by Task Forces [12], "Some Barriers to Teamwork in Social Research" [14], "Ethical Problems in Team Research: A Structural Analysis and an Agenda for Resolution" [30], "Interdisciplinary Team Work" [46], "Interdisciplinary Team Preproposal Management" [52], "The Effect of a 'Social Problem' Orientation on the Organization of Scientific Research" [61], "Group Dynamics of the Interdisciplinary Team" [84], "Problems in Interdisciplinary Policy Research and Management in Government" [92], "Phases Encountered by a Project Team" [96], and "Building an Interdisciplinary Team" [117].

On the basis of titles alone, several concepts and issues in IDR, such as "policy," "communication," "conflicts," "funding," and "innovation," appear to receive little attention. For this reason, we extend our analysis to the annotations themselves. An inspection of this content reveals that titles sometimes obscure what the IDR piece is all about. For example, categories of team research activities are developed in "Conflicts in Interdisciplinary Research" [13]; Birnbaum finds that IDR "is more appropriate for very difficult research questions and at early stages of the research process" in "Contingencies for Interdisciplinary Research" [23]; Boulding and Geertz, respectively, reflect on overcoming knowledge specialization [29, 50]; industry's IDR organization is extolled as a model of university-industry cooperation in "Science Futures: The Industrial Connection" [43]; the utility of a multidisciplinary approach to the study of "ill-structured" problems is discussed in "On the Methodology of the Holistic Experiment" [78]; and bibliometric indicators of IDR in biotechnology are offered in "Measuring European Scientific Capability in Biotechnology" [102].

A final approach to the classification of the IDR annotations focuses on the empirical content of the bibliography and the methods/techniques employed. Slightly more than one-third of the items (46/134) appear to be empirical studies, as opposed to editorial statements, essays, memoirs, or review articles. Listed in Table 4 are the methodological emphases within the empirical works. A combination of methods characterizes 18 items. These include papers citing the inevitability of differing epistemologies operating within IDR teams [28,88] to pronouncements of the virtues of multiple methods [17]. The other items within this category divide between case studies of single projects, departments, companies, or research units [11, 13, 26, 75, 90, 116, 128, 129] and items that detail cross-project, -unit, and/or -cultural findings. In most of these items, authors relate "what worked" in a context and conjecture as to the reasons for the success.

Modelling is the single-most favored technique, especially computerized models of, e.g., "expert group consensus" [54], problem-solving "cultures" [103], and the relationship between interdisciplinary cooperation and group size [113]. Mathematical models that synthesize components of IDR processes have also been attempted [85, 123]. Conceptual or verbal model-building was occasionally noted, as in Campbell's classic "fish-scale" model [33]. Examples of other methodologies used in the study of IDR are technology assessment [e.g., 70, 101], questionnaires/interviews [e.g., 32, 44], and observation in both a lab setting [39] and at sites in the field [107].

The examination of methods appearing in the annotations prompted a similar survey of cited theories. We were surprised to find very few explicit references to theoretical perspectives (though one paper addresses the problem of "interfield theories" [42]). General systems theory appears four times [e.g., 60]. Role theory frames four other items which define types of IDR actors: the "bridge scientist" [5], "adaptors" and "innovators" [65], field "switchers" and "retainers" [69], and the "primary-secondary group" hybrid [115]. Structuralism is prominent in Piaget's book [89], evolution theory in Toulmin's review article [12]; status concordance theory is tested in Gillespie and Birnbaum's analysis of academic IDR teams; dialectical inquiry as a theory of research practice is reviewed by Mitroff and Mason [79]; and a new theory, "paradigmatology," is formulated by Maruyama [74].

Overall, one might conclude that it is largely atheoretical, i.e., guided as much by pragmatic concerns and ad hoc perspectives as by systematic frameworks. Although such a conclusion overstates the lack of theory in the IDR literature, it does underscore the often implicit use of theory in specifying variables and relationships in the study of IDR.

A Research Agenda

With a bibliometric profile and content analysis of the IDR literature in hand, we can proceed to a research agenda that derives from it. Usually, such an agenda is tied to a community of IDR practitioners. What we outline here anticipates ways for building an interdisciplinary research knowledge base.

We begin with a three-dimensional conceptualization of IDR. All three dimensions were introduced above; they are merely reordered for presentation here. The first dimension encompasses barriers to the performance of IDR which reside in the individual researcher. These barriers have at least three components: epistemological, psychological, and disciplinary. Each of these reinforces the other--and militates against IDR cooperation.

Researchers are predisposed to view the world in certain ways. Part of their storehouse of what Polanyi calls "tacit knowledge" are axiomatic assumptions about science, inquiry, natural and social phenomena, etc. These assumptions constitute one's epistemology; they make some theories and methodologies more appealing than others. They also make certain research modes more intrinsically appealing than others, e.g., collaborative v. individual style, theoretical v. empirical study, lab v. field setting, quantitative v. qualitative analysis. Out of such deep epistemological stirrings springs the willingness to engage in multidisciplinary research. Psychologically, one's open-mindedness, ability to listen, propensity to give suppport, and general security enables researchers trained in disparate disciplines and intellectual traditions to interact--perhaps over a lengthy period of time--on a mutually interesting research problem or topic. Since disciplines socialize researchers to communicate to fellow disciplinarians, indeed subdisciplinary specialists, the incentive to abandon esoteric jargon to promote cross-disciplinary exchange is not great. The psychological costs exacted on those who attempt such exchange is often too much to bear.

The upshot of the first dimension is that barriers exist within the individual--barriers that are transmitted institutionally--which discourage participation in IDR. Neither internal motivations nor external rewards prepare the researcher for the role of IDR team member. Only idiosyncratic needs and experiences draw the researcher to such collaboration. Representative evidence of barriers, and their origins, can be found in [25, 26, 32, 39, 49, 53, 65, 77, 88, 103, 124]. Perhaps the most apt description of the barrier problem is Rose's classic title, "Disciplined Research and Undisciplined Problems" [98].

The second dimension of IDR is implicated by the first, i.e., the contexts in which IDR is done. The two contextualizing components are cultural and organizational. Culture, of course, can refer to a country or a sector where research is performed, e.g. industry. Countries have sponsored week-long conferences as well as year-long experiments to assess the role that IDR might play in problem-solving and alternative university structure [e.g., UNESCO, 1, 47; OECD, 36; Canada, 37, 66, 81, 94; United Kingdom, 80, 97; Poland, 132]. Likewise, appraisals of R&D carried out in "independent research centers," e.g., Rand and SRI [9]; industrial labs [materials science, 7; pharmaceuticals, 116]; in U.S. government agencies [92]; or under the auspices of Federal agencies [NASA and NSF/RANN, 27, 75 131] have highlighted sector-specific problems.

At the organizational level, the focus is those units within a sector which house research, e.g., programs, departments, centers, and laboratories. The literature subsumable under the dimension of context focuses on the impacts of motivations, pressures, structures, and rewards on individual research behavior. Although, as we have seen, the preoccupation has been with academic IDR, the portrait of the academic interdisciplinary researcher is ambivalent. On the one hand, the researcher is cast as a victim of the university--a "cultural outcast" [49] and erstwhile member of "the un-faculty" [67, 118]. On the other hand, the IDR worker is a savior--a "culture broker" [56], or euphorically, an "ideal polymath" [117]. We find such characterizations hyperbolic and rather wishful. Yet the IDR worker, at least in academe, does seem caught betwixt and between. Universities appear to be oppressive environments for IDR with little understanding or inclination to facilitate extra-departmental, multidisciplinary research [63, 64, 82]. University administrators are especially defensive, obdurate, and parochial in coping with the organizational challenges which IDR typically entails, be they budgetary [10, 48, 52] or structural and evaluative [19, 22, 105, 107]. Careers are surely not "launched" by participation in IDR projects; rather, those careers may be stifled by pursuits occurring outside the mainstream of disciplines. It is the established researcher, e.g., the tenured professor, who can afford to contribute without excessive risk.

The third dimension of IDR links its practice and performance to applications. The two components we stress are policy-formulation and pedagogy. The first asks how IDR affects outcomes--does anything change? Are findings based on IDR inquiry any more useful than disciplinary research? Is the problem-solving rhetoric voiced by interdisciplinary researchers borne out by deeds? Precious little evidence speaks to these questions. Documented success stories are rare [e.g., the design of inventions [7]. More common are works promising IDR-inspired "reform-mongering" [8], task force effectiveness at A.D. Little [12], success of a graduate program to apply technology assessment to the fossil-fuel problem [63], and 15 kinds of creative achievements [111].

The most discernible consensus-laden folk wisdom on the application of IDR products concerns the "integration" of specialists' skills and knowledge [22]. Indeed, integration is what makes IDR interdisciplinary. As Meeth [76] puts it, the "attempt to integrate the contributions of several disciplines to a problem, issue, or theme from life" is what distinguishes interdisciplinary from cross-, multi-, and transdisciplinary. It is the integration of interdisciplinary contributions that is claimed as a solution, for example, to environmental issues [38]. Linstone [70] argues that integration should be left to the "decision-maker"; Rossini and Porter [100] advocate integration at the project level; Toulmin [120] suggests that such details may be inconsequential anyway since, in the evolution of disciplines and knowledge specialization, "problem-oriented" issues will gain hegemony over "discipline-oriented" research and "will need about thirty years to develop their own specialized theoretical ideas and techniques..."

To most, the site of this development of IDR will still be the university. Where pedagogy prevails, utopian visions proliferate. A decade ago CERI [36] offered a "sample model of an interdisciplinary university." Jantsch [60], writing about the same time, proposed a "transdisciplinary university" in which "systems design laboratories" and "function-oriented departments" would coexist with "discipline-oriented departments." Long [71] made a similar plea in a Science editorial. More recently, Nelson [81] echoed the theme of initiating IDR training with undergraduate instruction by urging consideration of "replenishing our academic gene pool" with "interdisciplinary-oriented colleagues."

Nowhere is the vision fuller than in Roy's [104] assertion that "interdisciplinarity is inherent in the nature of reality." For Roy and many others [94], the "elusive dream" is an interdisciplinary science campus. As Nilles [83] explains (writing in 1975), "The universities have the unique advantage of being able to maintain a large pool of expertise which is not dependent for survival on externally funded research." The optimism of this statement, eclipsed by the resource situation of most universities, sounds worse than an "elusive dream" in 1983--it rings of illusion. Research universities are utterly dependent on external funding from government and industry alike. Interdisciplinary "experiments," it seems, must be fiscally self-sufficient, while the entrenched disciplinary departments--staffed by tenured faculties--command some continuing resource allocation.

Yet the dream has been financed to some extent. If it were not, we could not talk about the barriers, contexts, and applications of IDR. There would be no such animal--no literature to retrieve and no research agenda to compile. Clearly, that is not the case. Researchers on IDR have gained a certain legitimacy and visibility. They have formed an International Association for the Study of Interdisciplinary Research, publish a newsletter (INTERSTUDY), held two conferences [see 86], and are planning another for August, 1984. All the social trappings of specialization, in other words, are present for IDR.

Here, then, is a contemporary example of a scientific specialty which emanates from no single discipline, is endemic to no single setting (if anything, IDR--under various rubrics--thrives in nonacademic settings), and is not formally transmitted via a graduate degree-granting curriculum. Specialists in interdisciplinarity are self-selected and -identified "converts." What remains clouded is whether a purpose of interdisciplinary researchers is to counter the trend toward knowledge fragmentation and over-specialization. If this is an objective, then IDR may become a victim of the very trend it seeks to buck. That is, if it is to develop and compete for the mechanisms that sustain modern science--its own journals, associations, meetings, funding programs, and doubtless its soon-to-be-heralded orthodoxies and heroes--it will succumb to the same parochialism that insulates other intellectually-myopic specialties. As a community of researchers, IDR will take on the coloring of its chief authors, their disciplinary origins, and preferences of theory, method, and problem. The saving grace of IDR will be diversity--its collective ability to tolerate differences of approach and application.

Individual and institutional efforts to foster multidisciplinary cooperation, i.e., interaction without "integration," have already resulted in the emergence of several "interdisciplines." As Porter et al. [93] wrote in 1980:

> The presumption that 'science' is conducted solely within disciplines dominates establishment practices in funding research, publishing findings, and advancing careers. Unfortunately, this not only occasions cracks between disciplines, it fails to provide adequate bridges across intellectual and societal chasms.

If problems do not conveniently distribute themselves into the niches traditionally defined by disciplines, then scientific specialization can be seen as a bureaucratic creation--reified in the university department, for instance--instead of a sensible intellectual stratification for conceptualizing, studying, and acting on reality. The paradox, of course, is that the deeper one delves into an esoteric problem, the less "disciplinary" its dimensions become.

Many interdisciplines today have a decided policy focus, e.g., technology assessment, social and science indicators, information science, science studies, and bibliometrics. The overlap between these research domains and the IDR literature is obvious. Nevertheless, training in these interdisciplines occurs via research experience, not through doctoral study per se. This absence of systematic pedagogy suggests the following hypothesis: the subject matter of interdisciplines consists of urgent but ephemeral problems which themselves resist institutional treatment. Therefore, they require an adaptable form of intellectual organization that can mobilize the personnel and resources appropriate to solution, or at least mediation, of the problem. The essence of interdisciplinary research is the integration of subdisciplinary contributions to a team product. The product itself is an innovative blend of perspectives and analyses that have immediate utility to a particular audience of users, i.e., policy-makers.

Included in our research agenda for the IDR-inclined, then, must be some so-called reflexive or self-examination of the enterprise in which we are engaged, indeed which expands with every title containing keywords such as those reviewed earlier. Thus, we would urge consideration of the following:

1. Intellectual migration: where do interdisciplinary researchers come from? Which disciplines? Which journals have they published in and do they now utilize?

2. Training for interdisciplinary problem-solving: which skills need to be imparted? Who might teach them?

3. Local organizational behavior and cosmopolitan rewards: how can researchers be induced to undertake IDR? What incentives and rewards can the employers of IDR workers provide?

4. Assessing interdisciplines: how do they differ from disciplines, specialties, invisible colleges, networks, etc.? Are their norms, communication patterns, modes of collaboration and publication any different from other scientific collectivities?

5. Cognitive styles: Is there a psychological profile or set of traits which sets IDR workers apart from mainstream disciplinarians? Are they more entrepeneurial, less indulgent of dull colleagues, more theoretically-inclined, etc.?

These five sets of queries are shared for their heuristic value. They are ingredients for future study--whether under the rubric "multi-skilled, problem-focused" research or the more familiar academic designation "interdisciplinary" research--to be seasoned by the annotations which immediately follow. They are intended to whet the appetite and, yes, to attract converts to the IDR table.

We therefore urge you to share with us the novel uses to which you apply both the annotated bibliography and this book as a whole. We'd like nothing better than to discover new colleagues whose own parochial tendencies converge somewhat with our own. That is how we know thee, interdisciplinarity--by the complementary perspectives on mutual research problems that ignite new approaches and collaborative efforts.

Figure 1

Frequency (····) and Cumulative Frequency (——) Distributions

of 134 IDR Items

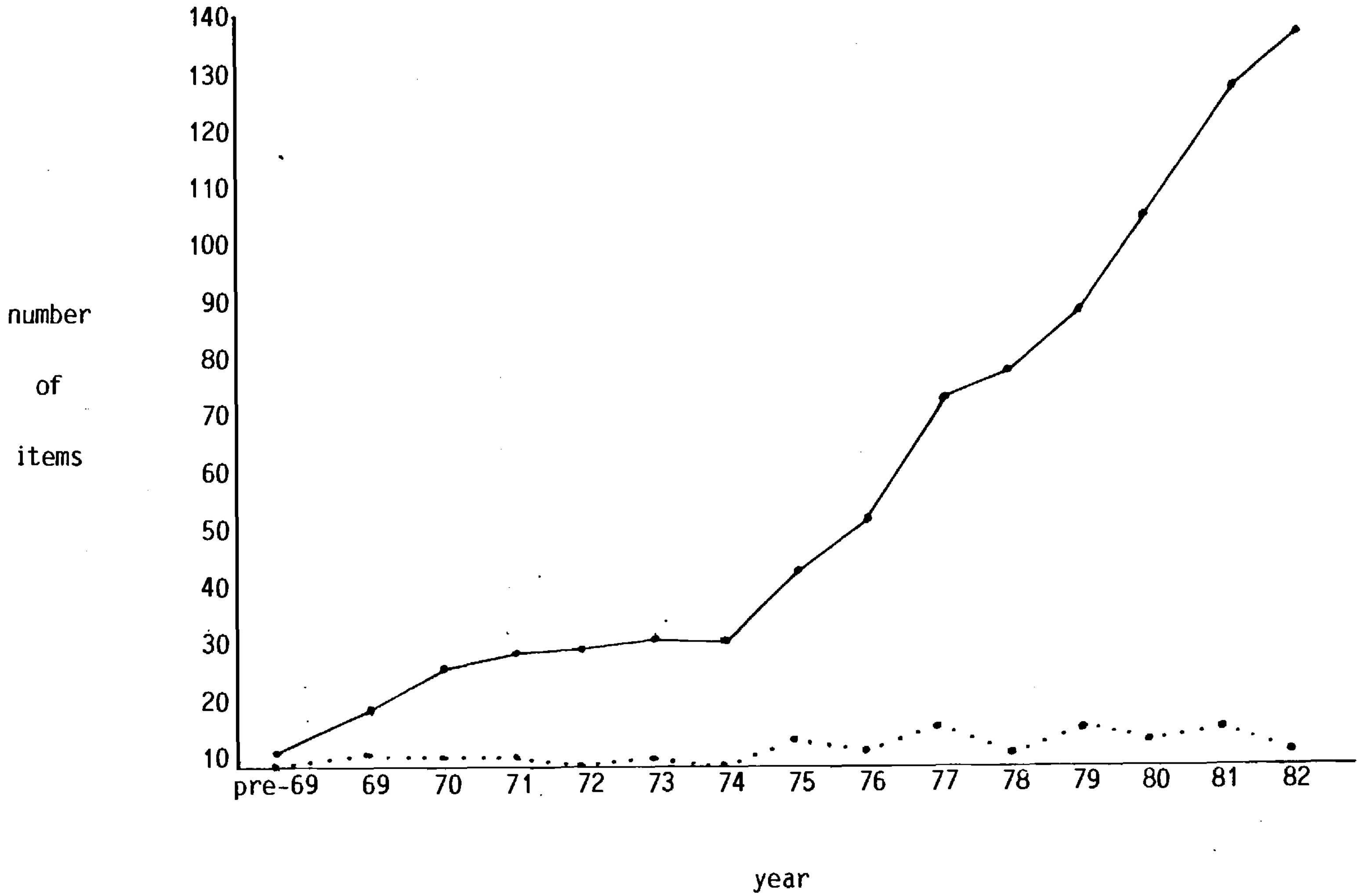

Table 1

Distribution by Publication Type
of 134 IDR Items, 1951-82

type	n	%
book	9	6.7
journal	98	73.1
chapter	14	10.4
report/ unpublished	13	9.7
total	134	99.9*

* rounding error

Table 2

Major Source Journals for IDR Items

journal	n
Journal of the Society of Research Administrators	9
R&D Management	4
Science	4
Daedalus	3
Engineering Education	3
International Social Science Journal	3
Policy Sciences	3
Technological Forecasting & Social Change	3
Academy of Management Journal	2
Management Science	2
total	36

Table 3

Most Frequently-Appearing Keywords in Titles of IDR Items

keyword	n
academic/university	25
management	15
team(work)	12
organization	9
discipline(s)	6
policy	4
communication	3
conflicts/pitfalls/ barriers	3
funding	2
government	2
innovation	2
applied	2
effectiveness	2

Table 4

Methodological Emphases in IDR Items*

method/technique	n of items
multiple/eclectic	18
modelling	10
technology assessment/ impact assessment	6
questionnaires/ interviews	4
(lab) observation	4

*based on annotations, not just title keywords

ANNOTATED BIBLIOGRAPHY

1. Abestalo, Marja, "Interdisciplinarity in the light of the development of science and the actual research work." In J. Farkas (ed.), Sociology of Science and Research. Budapest: Akademiai Kiado, 1979.

   A review of a cross-national UNESCO study of 219 research units. The emphasis is on different forms of interdisciplinarity, including "the interdisciplinarity of the research problem, the interdisciplinary diversity of R&D experience of scientists, the use of interdisciplinary theories and methods by members of research units, and the interdisciplinary contacts with other scientists."

2. Adler, L. L., "Plea for interdisciplinary cross-cultural research - some introductory remarks." The Annals (of the New York Academy of Sciences) 285 (March 1977): 1-2.

   Expresses the hope that interdisciplinary cross-cultural interaction among psychologists, anthropologists, and sociologists will be achieved.

3. Allen, T. Harrell, "Cross-impact analysis: A technique for managing interdisciplinary research." Journal of the Society of Research Administrators 9 (Summer 1978): 11-18.

   "The cross-impact method makes it possible to integrate the opinions of experts from different disciplines..." The cross-impact matrix "can serve as a testing ground for policies." General systems theory, and especially the interdependence of future events, guides the application of this method.

4. Alpert, D. The Role Structure of Interdisciplinary and Multidisciplinary Research Centers. Washington, D.C.: Council of Graduate Schools of the U.S., 1969.

   An essay, circa 1969, which admonishes that "if the university wants to address itself to today's problems, it must establish interdisciplinary centers which are administered, staffed, and run very differently from those of the present.

5. Anbar, Michael, "The 'bridge scientist' and his role." Research/Development (July 1973):

   Asserts that "bringing together professionals with different disciplinary affiliations generates profound problems of interpersonal communication." Suggests that "the successful performance of a 'bridge role' in the management of such teams may mitigate these problems." Distinguishes four types of bridge scientist and discusses training for the role.

* The base collection on which statistical compilations are based is numbered from 1-134. Additional entries appear unnumbered interspersed in alphabetical order.

6. Andrews, Frank M., "Motivation, diversity, and the performance of research units." In F. M. Andrews, (ed.), Scientific Productivity: The Effectiveness of Research Groups in Six Countries. Cambridge University Press, 1979.

A cross-national analysis of research units shows a significant diversity-performance relationship, where diversity refers to "R&D functions," "time allocations," "specializations," and "project commitments." Researcher motivation tends not to overlap with diversity in predicting the performance of research units.

7. Anonymous, Materials Science and Engineering, 37 (January 1979): 56-70.

Several short case descriptions of important interdisciplinary developments in materials science and engineering--including integrated circuits, coated stainless steel razor blades, synthetic fibers, transistors, and TV phosphors--provide a unique glimpse at the individuals, disciplines, organizational settings and problems that comprise this field.

8. Archibald, K. A., "Three views of the expert's role in policymaking: systems analysis, incrementalism, and the clinical approach." Policy Sciences 1 (1970): 73-86.

Approaches to "reform-mongering" based on interdisciplinary inspirations.

9. Baers, W. S., "Interdisciplinary policy research in independent research centers." IEEE Transactions on Engineering Management 23 (May 1976): 76-78.

Argues that "the major problems of managing interdisciplinary research projects include building a strong interdisciplinary team, selecting and motivating project leaders, maximizing institutional support selecting the right projects and clients, and linking research to policy-making." The focus is on "independent research centers," research institutions such as the Rand Corporation and the Stanford Research Institute not administered by universities, government agencies, or industrial firms.

10. Baldwin, Donald R. and Barbara J. Faubian, "Interdisciplinary research in the academic setting." Journal of the Society of Research Administrators 6 (Spring 1975): 3-8.

An overview of obstacles and suggestions for improved management of interdisciplinary research, including new budgeting and accounting methods, and better integration of the research and teaching functions.

11. Barmark, Jan and Goran Wallen, "The development of an interdisciplinary project." In K. D. Knorr, R. Krohn, and R. Whitley (eds.), The Social Process of Scientific Investigation, Sociology of the Sciences, Vol. 4. Dordrecht and Boston: D. Reidel, 1980: 221-235.

Case study of a forest project that examines "the different motives of the researchers for entering the project, the basic differences in outlook and personality between empirical and theoretical scientists, and the effects of the existing academic career structure" which threatens the solidarity of the research team. A major finding is that "integration of knowledge is dependent on integration at different stages of the research process."

Barth, Richard T. and Steck, Rudy (eds.), Interdisciplinary Research Groups: Their Management and Organization, First International Conference on Interdisciplinary Research Groups, Schloss Reisenburg, Federal Republic of Germany, 1979, available from Donald Baldwin, University of Washington, Seattle.

Twenty-two papers focused on the conduct of interdisciplinary research. These papers (some abstracted individually in this bibliography) provide a key basic source. They encompass self-reflection on how to study interdisciplinarity, conceptual frameworks, case studies and comparative research on interdisciplinary groups, and consideration of specific issues in industrial, university, and international research efforts.

12. Bass, Lawrence W., Management by Task Forces, Mt. Airy, Maryland: Lamond Books, 1975.

Subtitled "A Manual on the Operation of Interdisciplinary Teams," this book summarizes the wisdom of a former Arthur D. Little vice-president. The chapters on "Categories of Interdisciplinary Activities" and "Environment and Benefits of Interdisciplinary Teams," plus an appendix on "How to Start Task Force Systems," make this worthwhile reading for the interdisciplinarian--researcher or manager.

13. Bella, D. A. and K. J. Williamson, "Conflicts in interdisciplinary research." Journal of Environmental Systems 6 (1976-77): 105-124.

Case study of personnel conflicts developed in the course of an interdisciplinary project assessing the impacts of dredging on estuaries. Four categories of team research activities are identified with a risk or recognition factor attached to each. Methods of dealing with these factors are discussed.

14. Bennis, Warren G., "Some barriers to teamwork in social research." Social Problems 3 (April 1956): 223-235.

Factors which impede interdisciplinary social science research in the university include the language of disciplines, changes in team personnel, the use and misuse of group "findings," and autonomy vs. reliance on team members' work.

15. Benton, Douglas A., "Management and effectiveness measures for interdisciplinary research." Journal of the Society of Research Administrators 6 (Spring 1975): 37-45.

"The management characteristics most important to IDR effectiveness appear to be (1) Teamwork, (2) Competence of Professionals, (3) Morale, (4) Feedback and (5) Organizational Structure and Flexibility."

16. Benton, D. A., Meiman, J. R., Simons, D. B., Sjogren, D. D., Taylor, D. C., and McPhail, M. Organization and Personnel Management for Effective Interdisciplinary Research Projects, Colorado State University, Fort Collins, CO, Feb. 1977 (available through NTIS, PB 271 796), 349 pgs.

    This report develops management and effectiveness measures from theoretical bases in effective large scale interdisciplinary research projects. It examines the relationships for six projects at Colorado State University.

17. Berk, Richard A., "On the compatibility of applied and basic sociological research: An effort in marriage counseling." The American Sociologist 16 (November 19, 1981): 204-211.

    In a provocative essay that espouses reconciliation of basic and applied sociological research, the author advocates, among others, "an inter-disciplinary approach," the use of multiple methods, and "a team research effort." He argues that "applied research is routinely discriminated against by the profession's gatekeepers," and that "sociology surely would benefit from exposure to perspectives from other academic desciplines."

18. Birnbaum, Norman, "The arbitrary disciplines." Change (July-August 1969): 10-21.

    An historical examination of disciplines which "have become - despite our volition - means of perpetuating the irrationalities inherent in contemporary society's use of knowledge."

19. Birnbaum, P. H., "Academic interdisciplinary research: Problems and practice." R&D Management 10 (October 1979): 17-37.

    A profile of North American academic scientists engaged in interdisciplinary research includes the findings that they are younger (under 40) and either already tenured or not in tenure-track positions compared to their colleagues not engaged in interdisciplinary research. Interdisciplinary teams typically consist of five to six individuals and seldom for more than five years.

20. Birnbaum, P. H., "The organization and management of interdisciplinary research - a progress report." Journal of the Society of Research Administrators 13 (1982): 11-23.

    Reviews the state-of-the-art of IDR across academia, government, and industry in 11 nations. Sections include definitions, issues, a

framework for current research inputs, outputs, and a 62-item bibliography.

21. Birnbaum, P. H., "Assessment of alternative management forms in academic interdisciplinary reseach projects." *Management Science* 24 (1977): 272-284.

Large academic projects with a clear division of labor and centralized policy making were found to be associated with the highest performance levels. Planning time spent by the project leader was not significantly related to performance. A clear diagnosis of problems in administering interdisciplinary research projects does not emerge here.

22. Birnbaum, P. H., "Integration and specialization in academic research." *Academy of Management Journal* 24 (1981): 487-503.

Examines "integrating specialized experts from different disciplines in academic research projects." The hypothesis that "if academic research groups agree on the importance of research outputs as organizational goals, then higher performing groups will have fewer interdisciplinary characteristics and will be less integrated" is supported. Other findings indicate that interdisciplinary integration increases the difficulty in publishing the team's research and that interdisciplinary graduate training does not provide "readily marketable graduates for the scientific marketplace."

23. Birnbaum, P. H., "Contingencies for interdisciplinary research: Matching research questions with research organizations." *Management Science* 27 (November 1981): 1279-1293.

A study of the conditions under which interdisciplinary research helps to improve research performance in 67 ongoing academic interdisciplinary teams in the U.S. and Canada. The chief conclusion is that "interdisciplinary research is more appropriate for very difficult research questions and at early stages of the research process."

24. Birnbaum, P. H., Newell, W. T., and B. O. Saxberg, "Managing academic interdisciplinary research projects." *Decision Sciences* 10 (October 1979): 645-665.

Out of 40 variables suggested by the literature and experienced interdisciplinary research managers, two were found to predict high performance--"the longer an interdisciplinary research group stays together and encourages open discussion of disagreements."

25. Black, R. G., "The interdisciplinary communication problem - Its etiology and therapy." *The Trend in Engineering* 21 (January 1969): 10-18.

The problem exists between the engineer and the physician; course materials in biology and medicine are proposed to facilitate interdisciplinary relations.

26. Blackwell, G. W., "Multidisciplinary team research." Social Forces 4 (1955): 367-374.

Early reflections based on the author's experiences at the Institute for Research in Social Science at the University of North Carolina. Reviews "potential problems" and "adjustive mechanisms" in multidisciplinary team research.

27. Blankenship, L. V. and W. H. Lambright, "University research centers: A Comparison of NASA and RANN experiences." AAAS Conference Proceedings 76-R-8, American Association for the Advancement of Science, 1977.

An assessment of two programmatic strategies "to link portions of the scientific community into a research system whose output would be information and technology of applied relevance to problems of national concern."

28. Blunt, Peter, "Methodological developments in the social sciences: Some implications for interdisciplinary study." New Zealand Psychologist 10 (1981): 55-70.

A useful discussion, motivated by questions of epistemology and particularly Popper's falsificationist perspective, of methodology in psychology, social anthropology, and management theory. The author advocates the practice of a "methodological eclecticism" by social scientists in interdisciplinary fields such as organizational behavior. The eclecticism should begin at the epistemological level and extend to data analysis, informing the researcher of the "social engineering" potential of his/her methods.

29. Boulding, Kenneth E., "Science: Our common heritage." Science 207 (22 February 1980): 831-836.

An adaptation of the author's 1980 AAAS Presidential Lecture that traces knowledge specialization to a common scientific "heritage." Discusses images of science, including "the scientific method," and the relations between "secure" and "insecure" sciences. Concludes with a vision of the unity of human knowledge that is provocative as epistemological and cultural commentary.

30. Bradley, Raymond, T., "Ethical problems in team research: A structural analysis and an agenda for resolution." The American Sociologist 12 (May 1982): 87-94.

Discusses organizational needs and forms of team research "to guide prospective collaborators in the negotiation of a written agreement which will protect their individual rights and interests." Though narrowly sociological, the paper has direct relevance to interdisciplinary team composition and perhaps performance.

31. Burdge R. J. and P. Opryszek, "Interdisciplinary problems in doing impact assessment." Coping with Change: An Interdisciplinary Assessment of the Lake Shelbyville Reservoir, University of Illinois at Urbana: Institute for Environmental Studies, (June 1981): 349-359.

Documents an "interdisciplinary effort to examine the 'real' environmental impacts of the Lake Shelbyville (IL) reservoir ten years after it had begun operation." Among the issues explored are project funding, combatting disciplinary chauvinism, and the role of graduate students as team members.

32. Busch, Lawrence, "Disciplinary worlds of agricultural scientists: Scientific and societal implications." Annual Meeting, Rural Sociological Society, Guelph, Ontario (1981).

Examines the extent and implications of disciplinary insularity using data derived from a mail questionnaire sent to agricultural scientists at American state agricultural experiment stations and USDA laboratories. Among the findings germane to interdisciplinarity are: (1) disciplinary problems are likely to receive more support than those that cross disciplinary lines, and (2) the stock of knowledge produced by each of the disciplines may be divorced from that of other disciplines.

33. Campbell, Donald T., "Ethnocentrism of disciplines and the fish-scale of omniscience." In M. Sherif and C. W. Sherif (eds.), Interdisciplinary Relationships in the Social Sciences, Chicago: Aldine, 1969.

A conceptual forerunner of much empirical work on interdisciplinary problems and processes. Within the "fish-scale model," narrow intellectual specialties should overlap to form a comprehensive social science. Instead, due to the ethnocentrism of disciplines, we observe a redundancy among specialties that leaves interdisciplinary gaps. Campbell advocates the training of specialists in these interdisciplinary areas.

34. Cassell, Eric J., "How does interdisciplinary work get done?" In H. T. Engelhardt and D. Callahan (eds.), Knowledge, Value, and Belief. New York: The Hastings Center, (1977): 355-361.

A no-nonsense non-technical discussion of interdisciplinary group processes informed by observations made by an M.D. at The Hastings Center, New York.

35. Caudill, W., and B. H. Roberts, "Pitfalls in the organization of interdisciplinary research." Human Organization 10 (Winter 1951): 12-15.

An anthropologist and a psychiatrist discuss problems arising from their research collaboration, including "the pressure of publicity," "the common denominator of knowledge," and differences in "orientation to field work."

36. CERI, Interdisciplinarity: Problems of Teaching and Research in Universities. Paris: Organization for Economic Cooperation and Development, 1972.

A classic source of wisdom on interdisciplinarity based on a 1970 Seminar on Interdisciplinarity in Universities which was organized by OECD's Centre for Educational Research and Innovation in

collaboration with the French Ministry of Education and the University of Nice, France. The report features three parts: Opinions and Facts, Terminology and Concepts, and Problems and Solutions. The latter includes a "sample model of an interdisciplinary university" and a plan for "a center for interdisciplinary synthesis."

37. Chapman, I. and C. Farmi, "The funding of interdisciplinary research in Canada." Journal of Canadian Studies 15 (Autumn 1980): 30-33.

Emphases "the need to bring about a change in perception - not just in the government but in the Councils and the university community - of the value of interdisciplinary research. There seems at present little encouragement for the development of teams of experts...to help tackle the urgent problems facing Canada today."

38. Chen, R. S., "Interdisciplinary research and integration - The case of CO_2 and climate." Climatic Change 3 (1981): 429-447.

An interdisciplinary research program on the atmospheric carbon dioxide problem that ties into research on other social and environmental issues is advocated. The steps in such a program include the need to define "conceptual frameworks of climate/society interactions" a division of the problem into tractable parts that allows addressing "the role of information, evaluation, and choice at various levels," and the need "to develop flexible, innovative approaches to research management, with special emphasis on quality control, stable funding, professional opportunities, and interdisciplinary supervision."

39. Chubin, D. E., Rossini, F. A., Porter, A. L., and I. I. Mitroff, "Experimental technology assessment: Explorations in processes of interdisciplinary team research." Technological Forecasting and Social Change 15 (1979): 87-94.

Presents the results derived from laboratory simulations of mini-technology assessments. Observations of the TA team interactions reveal a preference for "common-group learning" as the method of problem-solution and an intellectual pecking-order that favors the (stereotyped) insights of the quantitative sciences.

40. Compton, W. D., "Multidisciplinary research." Physics Today 24 (1971): 11.

A letter that cautions "that a multidisciplinary research program will fall short of what each discipline would hope for, if that discipline were to examine the problem in its own way."

41. Coyne, Dermot P., "Horticulture and interdisciplinary research." Hortscience 14 (December 1979): 686.

A pep talk to horticultural scientists in which the author reminds that "interdisciplinary research is not new in agricultural experiment stations " ... [but] is also useful in basic research. For example in epidemiology, plant pathologists could cooperate with horticultural geneticists and microclimatologists."

42. Darden, L. and N. Maull, "Interfield theories." Philosophy of Science 44 (1977): 43-64.

Analyzes the generation and function of theories which bridge two fields of science. Examples from the history of modern biology are discussed, followed by their implications for understanding the unity and progress of science. Interdisciplinarity remains implicit throughout.

43. David, Edward, E., Jr., "Science futures: The industrial connection." Science 203 (2 March 1979): 837-840.

Focuses on the need for industrial-academic collaboration in research to enhance both U.S. innovation and economy. Industry's interdisciplinary research organization is advocated as a model.

44. Davis, W. E., III, Interdisciplinary Research in Theory and Practice: A View from the University. Syracuse University, April 1970 (NASA project available through NTIS, N70-33934), 157 pgs.

This master's thesis evaluates the NASA sustaining university program as to its success in meeting a key goal -- fostering interdisciplinary research in universities. Drawing on 56 interviews at 5 participating universities, it concludes that the program failed. The thesis explores the premises for interdisciplinary research and the essentials of university structuring. It blames several factors for the failure of the NASA program, including lack of university support for truly interdisciplinary research and that neither side seriously tried to attain that goal. Recommendations for organizational structuring and project managing are offered.

45. Delkeskamp, Corinna, "Interdisciplinarity: A critical appraisal." In H. T. Engelhardt and D. Callahan, (eds.), Knowledge, Value, and Belief. New York: The Hastings Center, 1977.

Reviews the relation of interdisciplinarity to ethics, especially philosophical foundations of the dialogue that separates scholars who consider this very relation.

46. DeWachter, M., "Interdisciplinary team work." Journal of Medical Ethics 2 (1976): 52-57.

Five years of experience as a member of a medical ethics team studying "fertility and sterility problems" frames the author's observations on patient contributions to the team's work.

47. di Castri, Francesco, "International, interdisciplinary research in ecology: The case of the man and the biosphere (MAB) programme." Human Ecology 4 (1976): 235-246.

Implementing this UNESCO program illustrates "both the potential and the limitations of integrated, international ecological research programs." One imperative for success is that "research workers in various natural and social sciences disciplines and the administrative decision-makers must share responsibility for planning and execution."

48. Fenner, E. H., "A project accounting system that encourages multidisciplinary research." Engineering Education 71 (November 1980): 167-169.

Describes the overcoming of budgetary and accounting obstacles to cross-department research projects at Texas A&M. A "dual accounting system" seems to provide "the proper climate and incentives for interdisciplinary research in educational institutions."

49. Gaff, Jerry, A. and Robert C. Wilson, "Faculty cultures and interdisciplinary studies." Journal of Higher Education 42 (1971): 186-201.

A survey of university faculty reveals, among other things, that (1) "most interdisciplinary efforts must be staffed by 'cultural outcasts,' faculty who have resisted narrow cultural conditioning...(and) are not easy to locate," and (2) "interdisciplinary programs typically pass through a period of adjustment" while faculty members choose to realize their commonly shared values in different ways.

50. Geertz, Clifford, "Blurred genres: The refiguration of social thought." American Scholar 56 (Spring 1980): 165-179.

A trenchant essay on the scope of disciplinary provinces, knowledge, and methods and how they might be connected to provide rich interpretations of social systems.

51. Gillespie, D. and P. Birnbaum, "Status concordance, coordination, and success in interdisciplinary research teams." Human Relations 33: (1980) 41-56.

Tests a theory on a sample of 67 ongoing interdisciplinary research teams in universities. The authors conclude that team success is not determined by status of participants alone, and that external status criteria are not important in the coordination of teamwork.

52. Gillespie, D. F. and B. Mar, "Interdisciplinary team preproposal managment." Journal of the Society of Research Administrators 9 (Fall 1977): 33-40.

Focus on inchoative teams engaged in the development of large-scale research proposals. Success was defined as "gaining financial support for the project." Among the findings are: (1) "seed money" is a prerequisite for success, though increasing the amount does not increase team effectiveness; and (2) successful preproposal teams enjoy consensus on goals.

53. Goodwin, William M., and William K. LeBold, "Interdisciplinarity and team teaching." Engineering Education 66 (December 1975): 247-254.

A classroom study to evaluate and "improve the social dimensions of engineering practice." The most elusive objective remains development of an interdisciplinary approach to problem-solving.

54. Gumnick, J. L., Appan, S. G., and C. S. Dunn, "Computerized mind support to interdisciplinary consensus formation processes." Journal of Energy and Environment 1 (September 1982): 37-60.

How the modeling of "expert group consensus" can improve decision-making. Such "knowledge engineering" utilizes artificial intelligence capabilities.

55. Gusdorf, G., "Past, present and future in interdisciplinary research." International Social Science Journal 29 (1977): 580-599.

A French historian warns that "the appeal to interdisciplinarity is seen as a kind of epistemological panacea, designed to cure all the ills the scientific consciousness of our age is heir to." He goes on to show that the appeal is ancient.

56. Hegedus, David M., "The Novel Experiment." Sloan School of Management, M.I.T., Working Paper 1102-80 (February 1980).

Provocative case study of the academic department as "the arena where intellectual forces from several disciplines meet to locally define (and re-define) the academic discipline." Among the issues discussed are "domestic and imported modes" of integrating new content, loyalty, turf defense, and the department as culture broker.

57. Henshel, Richard L., "Effects of disciplinary prestige on predictive accuracy: Distortions from feedback loops." Futures (April 1975): 92-106.

Explores the relationship "between predictive power and disciplinary prestige," focusing on the social sciences. The implications of this relationship in multidisciplinary projects -- for the interpretation and receptivity of findings -- are intriguing.

58. Hopeman, Richard J., and David L. Wilemon, "Reflecting on interdisciplinary research." Syracuse University, occasional paper prepared for NASA and available as NASA document N70-18480, 1970.

This little think piece is notable for 14 recommendations to improve the performance of interdisciplinary research in academic settings. These should be of interest as practical guidance and as potentially testable hypotheses for those studying interdisciplinary research processes.

59. Ikenberry, Stanley O., and Renee C. Friedman, Beyond Academic Departments: The Story of Institutes and Centers. San Francisco: Jossey-Bass, 1972.

A study of 125 university institutes, centers, and other research units created to foster multi- and interdisciplinary collaboration and problem solving. As an alternative to academic departments, institutes multiplied in the 1970s but created new problems of organization and administration.

60. Jantsch, Erich, "Inter- and transdisciplinary university: A systems approach to education and innovation." Policy Sciences 1 (1970): 403-428.

A transdisciplinary structure for the university is briefly outlined; "its main elements are three types of organizational units - systems design laboratories, function-oriented departments, and discipline-oriented departments - which focus on the interdisciplinary coordination between...method and organization."

61. Kamen, Charles S., "The effect of a 'social problem' orientation on the organization of scientific research." Journal of Environmental Systems 7 (1977-78): 309-322.

A survey of Israeli scientists and engineers involved in research on environmental quality problems shows that those who define their topics as having social relevance are more likely to employ an interdisciplinary orientation than those who do not.

62. Kaplan, M. B., "The case of the artificial heart panel." Hastings Center Report 5 (October 1975): 41-48.

The case is presented as an example of "lay participation in medical policy-making." The paper poses two questions about the interdisciplinary panel and its deliberations: "In what capacity were its members acting, as professional experts applying the skills of their disciplines, or as citizens exercising personal wisdom or representing community values?...Could the task of informing NHLI (National Heart and Lung Institute) as to the non-medical consequences of the device be separated from the evaluation of those consequences?"

63. Kash, D. E., "Observations on interdisciplinary studies and government roles." In R. Scribner and R. Chalk (eds.), Adapting Science to Social Needs. Washington, D.C.: AAAS, 1977: 147-167.

Presents a summary of a study of off-shore oil and gas conducted by the Science and Public Policy Program at the University of Oklahoma, one of the first established to do technology assessment. It became noted for its successful interdisciplinary research. The second part of the paper discusses "the institutional levers necessary if a university is to have much chance of carrying out interdisciplinary problem-oriented research."

64. Kast, F. E., J. E. Rosenzweig, and J. W. Stockman, "Interdisciplinary programs in a university setting." Academy of Management Journal 13 (1970): 311-324.

A report on "organizational and administrative problems associated with interdisciplinary research programs," as illustrated by the Ceramic Materials Research Program at the University of Washington. A major conclusion: "interdisciplinary research often requires that a hybrid form of organization structure be developed to compensate for obstacles inherent in the university setting."

65. Kirton, Michael J., "Adaptors and innovators." Planned Innovation (March/April 1980): 51-54.

Presents a theory of the way people approach problems -- either as "adaptors" or "innovators." The paper includes a description of the behavior of each type in a group context.

Kloza, Marian, Sztukowski, Czeslaw, and Wasniowski, Ryszard (eds.), Management of Research, Development and Education, IV International Conference Proceedings, Wroclaw, Poland: Futures Research Center of Wroclaw Technical University (No. 13), 1980. Includes eleven papers relating to interdisciplinary research. Issues in the conduct of such research in planned economies, the CMEA nations, come forth as relevant to counterpart research in the "free" economies. International cooperation is explicitly addressed in one paper; papers consider the performance of team research in university (Poland) and industrial (Sweden) settings; and two papers offer conceptual frameworks to study interdisciplinary research.

66. Kockelmans, Joseph (ed.), Interdisciplinarity, New Experience in Higher Education. University Park, Penn.: Pennsylvania State University Press, 1979.

Eleven essays on disciplinarity and interdisciplinarity, including curricula, methodology, personal and institutional problems. A "selective listing of interdisciplinary (degree) programs" in Canada and Western Europe is appended. In all, a good source book for the serious interdisciplinarian.

67. Kruytbosch, C., and S. L. Messinger, "Unequal peers: The situation of research at Berkeley." American Behavioral Scientist 11 (1968): 33-43.

The second-class citizenship of "researchers" with non-faculty appointments emerges from this Berkeley survey. While not on interdisciplinarity per se, the paper recognizes that "the recent growth of researcher ranks at major universities represents the emergence of a new academic role," and anticipates problems of teamwork, evaluation, and reward entailed by this new role.

68. Lenk, Hans and Gunter Ropohl, "Toward an interdisciplinary and pragmatic philosophy of technology: Technology as a focus for interdisciplinary reflection and systems research." Research in Philosophy & Technology 2 (1979): 15-52.

A long review article that synthesizes "philosophical and technological efforts at description, explanation, and interpretation, which are devoted to basic problems of technology." A section is devoted to "Methodology, Interdisciplinary Cooperation, and 'Technocracy'."

69. LePair, C. "Switching between academic disciplines in universities in the Netherlands." Scientometrics 2 (May 1980): 177-191.

Field "switchers" and "retainers" in the Netherlands university system, and their implications for informing neighboring scientific disciplines and assessing interdisciplinary merit, are examined empirically.

70. Linstone, H. A. et al., "The multiple perspective concept: With applications to technology assessment and other decision areas." Technological Forecasting and Social Change 20 (1981): 275-325.

An empirically-based conceptual paper that concludes with useful "guidelines to assist assessors, forecasters, policy analysts, and other users." Among the most provocative are: "Form the team to assure an interparadigmatic mix rather than merely an interdisciplinary mix" (i.e., the team needs individuals who have been nurtured on different inquiring systems); "Understand the quasicontinuous range of perspectives from the personal to the large formal organization"; and "In most cases, leave the integration of the perspectives to the user or decision maker, but do point out cross-cuing links among them."

71. Long, F. A., "Interdisciplinary problem-oriented research in the university." Science 171 (12 March 1971):

Editorial that declares "the most important reason why the universities must become involved in interdisciplinary research...is their obligation to youth. ...College students must learn a genuinely interdisciplinary approach..."

72. Luszki, Margaret Barron, Interdisciplinary Team Research: Methods and Problems. Washington, D.C. National Training Laboratories, National Education Association, 1958.

A classic analysis of interdisciplinary research successes and failures.

73. MacDonald, William R., "The management of interdisciplinary research teams: A literature review." Report of the Department of the

Environment and the Department of Agriculture, Government of Alberta, Edmonton, Alberta, Canada (January 1982).

An attempted synthesis of findings on "factors influencing team performance," "problems with teams," and "problems with the literature." Among the latter, the author observes little attention paid to interdisciplinary teams in nonacademic organizations and "a lack of insight into social issues" such as the need for "new expertise" and the development of "team skills." A perceptive and well-written document.

74. Maruyama, Magorab, "Paradigmatology and its application to cross-disciplinary, cross-professional, and cross-cultural communication." Cybernetica (1974): 136-156, 237-281.

A treatise, in two parts, on the origins of "paradigmatology" as a "science of structures of reasoning which vary from discipline to discipline, from profession to profession, from culture to culture, and sometimes even from individual to individual." Part II relates paradigms to social organization and perception, extolling "non-disciplinary programs, decategorization of science and transspecialization." If one can tolerate the neologisms, this is an exemplary discussion by a polymath unchained.

75. McEvoy, James III,"Multi- and interdisciplinary research--Problems of initiation, control, integration and reward." Policy Sciences 3 (1972): 201-208.

Outlines the author's "experience as project director of a large interdisciplinary project concerned with man's effects on Lake Tahoe." The difficulties of conducting the project under the NSF-RANN definition of "national need" are described.

76. Meeth, L. Richard, "Interdisciplinary studies: A matter of definition." Change 7 (August 1978): 10.

An editorial that describes an "interdisciplinary pyramid." Intra-disciplinarity forms the basis, with cross-disciplinary courses ("observing one discipline from the perspective of another") a level above, multi-disciplinary ("several disciplines focused on one problem or issue") one higher, interdisciplinary ("attempt to integrate the contributions of several disciplines to a problem, issue, or theme from life") at the next level, and transdisciplinary ("beyond the disciplines ... programs start with the issue or problem") at the highest level.

77. Milgram, Stanley, "Interdisciplinary thinking and the small world problem." In M. Sherif and C. W. Sherif (eds.), Interdisciplinary Relationships in the Social Sciences. Chicago: Aldine, 1969.

Contains conjectures on which stages in the research process "interdisciplinary thinking" can be useful.

78. Mitroff, I. I. and L. V. Blankenship, "On the methodology of the holistic experiment: An approach to the conceptualization of large-scale social experiments." Technological Forecasting & Social Change 4 (1973): 339-353.

Proposes a multidisciplinary approach to "ill-structured" problems. The guidelines for a holistic methodology include "at least two 'radically distinct' disciplines of knowledge, ... kinds of conceptualizers, ... [and] philosophical inquiry models."

79. Mitroff, I. I. and R. O. Mason, "Dialectical pragmatism: A progress report on an interdisciplinary program of research on dialectical inquiring systems." Synthese 47 (1981): 29-42.

The philosophy and methodology of the "dialectical inquirer" are reviewed as an interdisciplinary theory of social scientific practice.

80. Mooney, G. H. and A. H. Williams, "Economists in multidisciplinary teams: Some unresolved problems in the conduct of health services research." Social Science and Medicine 14 (1980): 217-221.

Report of a meeting at the University of Aberdeen, U.K., that brought together five multidisciplinary research teams "to discuss the problems involved in integrating economics and economists into multidisciplinary research teams in health care." Two notable findings: "The economists complained about the difficulty of getting statistical ideas across to doctors, and felt that there should be some obligation on 'the system' to improve its own receptivity to economic argument." Also, "it was unclear who was the 'client' for health services research with an economic component."

81. Nelson, Neil, "Issues in funding and evaluating interdisciplinary research." Journal of Canadian Studies 15 (Autumn 1980): 25-29.

Argues that IDR contributes three things "to scholarship and to society": "gap-bridging," "synergy," and "problem-solving." This paper reports on two workshops convened in 1978 and 1979 by the Human Environment Committee of the Social Science Federation of Canada. Each workshop focused on the research team reward systems, and evaluating both proposals and outcomes. Considerations of "replenishing our academic gene pool" with "interdisciplinary-oriented colleagues" are raised.

82. Nilles, J. M., "Interdisciplinary research and American university." Interdisciplinary Science Reviews 1 (1976): 160-166.

Addresses the central question "Can interdisciplinary research be managed effectively at a university in the United States?" The perspectives of several actors at this site are considered: administrator, educator, faculty researcher, research manager, donor of external funding, and ultimate user of the research. A series of recommendations are included.

83. Nilles, J. M., "Interdisciplinary research management in the university environment." Journal of the Society of Research Administrators 6 (Spring 1975): 9-15.

After outlining the difficulties of managing interdisciplinary research at the university, the author waxes optimistic: "The universities can provide the detachment from the immediate pressures of certain short term first order applications and special interest goals...which is so necessary for effective IDR. The universities have the unique advantage of being able to maintain a large pool of expertise which is not dependent for survival on externally funded research. They are beginning to realize this strength and take effective measures to develop it." Unfounded optimism?

84. Odhner, Fred, "Group dynamics of the interdisciplinary team." American Journal of Occupational Therapy 24 (October 1970): 484-487.

Reviews T-group process and its application to interdisciplinary interaction and "the effectiveness of the health team," not research per se.

85. Paelinck, Jean H/P. (ed)., Issues in Interdisciplinarity, Proceedings of a Seminar, Rotterdam Institute for Multi-and Interdisciplinary Research (RIMIR), Erasmus University, Rotterdam, The Netherlands, 1982.

Features ten papers, four on "fundamental issues" and six "applications" to psycho-medicine, spatial analysis, statistical modelling, and medical care. An eleventh, purported synthesis afterward by the econometrician-editor fails to consolidate the diverse, largely quantitative contributions that precede it.

86. Payne, Roy and Alan Pearson, "International Conference on Management of international comparison of their organization and management." R & D Management (1979): 35-37.

A summary report on the first International Conference on Managment of Interdisciplinary Research held in Schloss Reisensburg, West Germany, in April 1979. Thirty experts representing 10 countries participated. The importance of developing evaluation measures of interdisciplinary research was stressed.

87. Peston, Maurice, "Some thoughts on evaluating interdisciplinary research." Higher Education Review 10 (1978): 55-60.

"The key issue is a somewhat paradoxical one of preventing the interdisciplinary project from being destroyed by the competing claims of the individual disciplines while providing for it some appropriate foundation which to put the point in its crudest terms, enables it to be 'academically respectable'." According to Peston, "the trouble is simply that...we have no subject called interdisciplinary science, and, therefore, no resting home for our results."

88. Petrie, H. D., "Do you see what I see? The epistemology of interdisciplinary inquiry." Journal of Aesthetic Education 10 (1976): 9-15.

Reports the experience of an interdisciplinary faculty group discussing "the interdisciplinary research and teaching process." Considers participants' psychological characteristics, institutional setting, and Polanyi's notion of "tacit knowledge." Suggests that metaphor may be a key to bridging the categories and concepts of different disciplines.

89. Piaget, Jean, Main Trends in Interdisciplinary Research. London: Allen and Unwin, 1973.

A structuralist approach to IDR. Locating responsibility for developing IDR in the "human sciences," the author declares that "to reshape or reorganize the fields of knowledge by means of exchanges which are in fact constructive recombinations" or hybridizations. Examples include psycholinguistics, social psychology, and ethology.

90. Pignataro, L. J. and W. R. McShane, "Interdisciplinary research - transcending departmental conflicts." Engineering Education 69 (January 1979): 349-351.

A discussion based on the Transportation Training and Research Center at the Polytechnic Institute of New York.

91. Pilet, P. E., "The multidisciplinary aspects of biology - basic and applied research." Scientia 116 (1981): 629-636.

Building on the "interdisciplinary nature" of biology, the author, (translated from the French) expounds on the need for "centers devoted especially on research into research," and on researchers' "dialectical reflection upon...the reasons underlying their intellectual activity."

92. Polishuk, Paul, "Problems in interdisciplinary policy research and management in government." IEEE Transactions on Engineering Management 23 (May 1976): 92-100.

Interdisciplinary research is seen as appropriate for establishing "a telecommunications policy analysis function within the U.S. Department of Commerce." A detailed guide to managing interdisciplinary policy research is provided.

93. Porter, A. L., Rossini, F. A., Chubin, D. E., and T. Connolly, "Between disciplines." Science 209 (29 August 1980): 966.

Letter lamenting the lack of NSF funding for research that studies interdisciplinary problems and processes.

94. Porter, Arthur, "Expansion of transdisciplinary studies." Transactions of the Royal Society of Canada 11 (1973): 11-20.

After praising academic departments, the author considers the administration of transdisciplinary studies. He concludes that "faculty members...who undertake transdisciplinary teaching, research, and service to the community should be encouraged and rewarded appropriately," and "existing administrative arrangements ... should be reassessed in the light of increasing interest in mission-directed activites. Perhaps an interdisciplinary division should be added to the traditional divisions of graduate faculties."

95. Rajagopal, R., "Interdisciplinary research and education for ecosystems Management." Urban Systems 4 (1979): 43-52.

Discusses the scope and limitation of systems analysis as a framework for integrating varied disciplinary efforts in resource and environmental management.

96. Riley, M. W., "Phases encountered by a project team." IEEE Transactions on Education 23 (November 1980): 212-213.

Seven phases of interdisciplinary study that "all engineers" will encounter "sometime during their career" are outlined. They are: initial enthusiasm, data gathering, group divergence, group convergence, group panic, group effort, and group accomplishment.

97. Robertson, Ivan T., "Some factors associated with successful interdisciplinary research." Journal of the Society of Research Administrators 13 (Fall 1981): 44-50.

A preliminary analysis of 150 interdisciplinary research projects conducted within manufacturing or service organizations in the U.K. Emphasis is on psychological and personal characteristics of the individual researchers.

98. Rose, Richard, "Disciplined research and undisciplined problems." International Social Science Journal 28 (1976): 99-121.

Examines "the organizational causes of the uneasy relationship between social scientists and government officials and the extent to which the intrinsic character of the 'undisciplined' problems of contemporary societies make this relationship both relevant and difficult." Multi- and interdisciplinary research approaches are proposed to relieve the difficulty.

99. Rossi, P. H., "Researchers, scholars, and policy makers: The politics of large-scale research." Daedalus 93 (1964): 1142-1161.

Considers "the organizational consequences of the development of research centers within the university environment." Much of this has been superseded by the creation of "organized research units" in the late 1960's and '70s, but this paper foreshadows such innovations without discussing interdisciplinarity per se.

100. Rossini, F. A. and A. L. Porter, "Frameworks for integrating interdisciplinary research." Research Policy 8 (1979): 70-79.

Summarizes the findings of a two-year, NSF-supported study of the process of integrating the disciplinary components of technology assessment (TA) projects. Findings include factors affecting project integration, especially communication pattern, leadership style, and "intellectual distances" between team members. Recommendations for integrating TAs stress "organizational context," "structural and process factors," and "frameworks for performing TA components."

101. Rossini, F. A. and A. L. Porter, "Interdisciplinary research: Performance and policy issues." Journal of the Society of Research Administrators 13 (Fall 1981): 8-24.

A conceptualization of interdisciplinary research that argues for its growth and significance. Among the issues discussed here are approaches to the social and intellectual organization of a TA, a causal model of TA integration, and institutional arrangements that affect interdisciplinary research performance and proposed problem solutions.

Rossini, F. A., Porter, A. L., Kelly, P., and Chubin, D.E., "Interdisciplinary Integration Within Technology Assessments." Knowledge: Creation, Duffusion, Utilization 2, 1981, 503-528. An empirical study of factors affecting the degree of interdisciplinary integration achieved in 24 technology assessments supported by the National Science Foundation.

102. Rothman, Harry, "Measuring European scientific capability in biotechnology." Presented to the FAST Biosociety Meeting, Brussels (March 1982), mimeo: Technology Policy Unit, University of Aston, U.K.

Intriguing tidbits on interdisciplinary research based on various literature-based indicators, including journal and national citation patterns, in the area of biotechnology.

103. Rouse, William B., "On models and modelers: N cultures." IEEE Transactions: Man, Systems, and Cybernetics SMC-12 (September/October 1982): 605-610.

Multidisciplinary problem-solving is contrasted with disciplinary perspectives. Three dimensions are seen as barriers to disciplinary solutions: age of discipline, nature of the phenomena investigated, and "intellectual world within which the discipline operates." Systems engineering, the author concludes, spans the boundaries of problems, disciplines, and solution, rendering it the ideal interdiscipline.

104. Roy, Rustum, "Interdisciplinary science on campus--the elusive dream." C&E News (29 August 1977): 28-40.

Asserting that "interdisciplinarity is inherent in the nature of reality," especially that part of it dealing with the problems of society, the author proposes models for creating interdisciplinary units on campus, their relationship to departments, and resource needs.

105. Russell, Martha Garrett (ed.), Enabling Interdisciplinary Research: Perspectives from Agriculture, Forestry, and Home Economics Miscellaneous Publication - 19, Agricultural Experiment Station University of Minnesota, 1982.

A provocative four-part collection plus a 48-item annotated bibliography. The two dozen chapters are capped by the editor's thoughts on evaluating IDR: "It explores the need to employ multiple assessment criteria so as to maintain both disciplinary rigor and interdisciplinary relevance."

106. Salmon-Cox, Leslie and Burkart Holzner, "Managing Multidisciplinarity: Building and Bridging Epistemologies in Educational R&D." Presented to American Educational Research Association (April 1977): mimeo.

Building a multidisciplinary environment in an academic setting "requires both strategies of resocialization and organization." An application to a Learning Research and Development Center is offered.

107. Saxberg, B. O., Newell, W. T., and B. W. Mar, "Interdisciplinary research - A dilemma for university central administration." Journal of the Society of Research Administrators 13 (Fall 1981): 25-43.

Based on site visits to major research universities, the authors report on problems related to "organized research units," e.g., institutes and centers. In general, there is an absence of policies or procedures for recognizing interdisciplinary research efforts and rewarding them relative to "single discipline/single investigator" projects.

108. Schneider, Stephen H., "Climate change and the world predicament: A case study for interdisciplinary research." Climatic Change 1 (1977): 21-43.

Presents a rationale for an interdisciplinary treatment of climate change. Discusses obstacles to and opportunities for the performance of interdisciplinary research, including how to foster it in the university.

109. Sharp, James M. and James L. Gumnick, "A method for peer group appraisal and interpretation of data developed in interdisciplinary research programs." Journal of the Society of Research Administrators 13 (Fall 1981): 51-66.

Report of insights gained by Gulf Universities Research Consortuim after 16 years of operation, and particularly, how "peer groups" are used to frame and perform interdisciplinary projects.

110. Sherif, Muzafer and Carolyn W. Sherif, "Interdisciplinary coordination as a validity check: Retrospect and prospects." In M. Sherif and C. W. Sherif (eds.), Interdisciplinary Relationships in the Social Sciences. Chicago: Aldine, 1969.

Reviews the utility of interdisciplinary work in the social sciences.

111. Simonton, Dean Keith, "Interdisciplinary creativity over historical time: A correlational analysis of generational fluctuations." Social Behavior and Personality 3 (1975): 181-188.

The interdisciplinary relationships among 15 kinds of creative achievements are examined "over 130 generations of European history." Three major interdisciplinary clusters are found: "(a) discursive (science, philosophy, literature, and music), (b) presentational (painting, sculpture, and architecture), and (c) rationalism - mysticism (physical science and general philosophy versus religion and painting)." Among the possible explanations given is that "because scientists, philosophers, poets, and even ... musicians all employ 'discursive' writing as a communicative medium, creativity in any one discipline may encourage creative activity in others."

112. Sinaceur, M., "What is interdisciplinarity?" International Social Science Journal 29 (1977): 572-579.

An editorial statement hailing the study of interdisciplinarity as a problem in its own right.

113. Steck, R. and J. Sundermann, "The effects of group size and cooperation on the success of interdisciplinary groups in R&D." R&D Management 8 (1978): 59-64.

Tests a mathematical model of the "relationships between cooperation among researchers and the chances of success interdisciplinary groups may have." Team size and internal structure of research groups emerge as significant correlates of success.

114. Steck, R., "How can research on research contribute to a better management of university research?" R&D Management 6 (February 1976): 81-86.

Reports on the "Sonderforschungsbereich 79, a large interdisciplinary academic research unit concerned with 'water research in the coastal area'." The results of this experiment to involve "research on research" scientists with specialists in the subject under investigation appear worthwhile for informing participants about management problems in research organization.

115. Stone, Anthony R., "The interdisciplinary research team." Journal of Applied Behavioral Science 5 (July 1969): 351-365.

A role analysis of the interdisciplinary team as an interacting task-oriented group. Groups are discussed as approximating, and often combining, the characteristics of primary - and secondary - group ideal types.

116. Stucki, J. C., "A goal oriented pharmaceutical research and development organization: An eleven year experience." In R. T. Barth and R. Steck (eds.), Interdisciplinary Research Groups: Their Management and Organization, (1979).

Upjohn Company's pharmaceutical R&D organization is compared "then and now." Multidisciplinary organization and decentralized leadership are seen as central for product discovery, development, and commercialization.

117. Taylor, James B., "Building an interdisciplinary team." In S. R. Arnstein and A. N. Christakis (eds.), Perspectives on Technology Assessment. Jerusalem: Science and Technology Publishers, 1975: 45-60.

Presents a profile of the "ideal polymath" and his/her role in interdisciplinary problem-solving.

118. Teich, A. H., "Trends in the organization of academic research: The role of ORUs and full time researchers." In R. T. Barth and R. Steck (eds.), Interdisciplinary Research Groups: Their Management and Organization, (1979).

A empirical study of the "organized research unit" within U.S. universities. ORUs operate outside of discipline-centered departments, usually have large-scale facilities, and are problem-oriented (in a multidisciplinary sense). Such campus-wide institutes, centers, or programs present challenges to traditional organizational structures, rewards, and personnel. Of particular interest is what Teich terms "the unfaculty."

119. Thomas, Dorothy Swaine, "Experiences in interdisciplinary research." American Sociological Review 17 (December 1952): 663-669.

The author's presidential address to the American Sociological Association stresses the connections, derived from 30 years of research experiences, between economics and sociology, theory and data.

120. Toulmin, Stephen, "From form to function: Philosophy and history of science in the 1950s and now." Daedalus 106 (Summer 1977): 143-162.

An intellectual history, partly autobiographical, in which the author traces the parallel developments of the history and philosophy of science in the 1950s and before to their convergence, if not interdisciplinary synthesis, beginning in the mid-1960s. The author, an evolutionary thinker, sees "problem-oriented" issues as gaining precedence over "discipline-oriented" research, and boldly predicts that "after a generation of concentration on interdisciplinary, concrete issues, new constellations of technical problems will be abstracted out to serve as the foci of new disciplines; and these will then need about thirty years to develop their own specialized theoretical ideas and techniques..."

121. Valaskakis, K., "Rewards and tribulations of interdisciplinary futures studies." Industrialization Forum 6 (1975): 41-46.

Within the context of "an interdisciplinary study of the problems and repercussions of conservation policies in a 'consumer' society," the author declares interdisciplinarity "virtually indispensable for futures studies." The avoidance of "discipline-imperialism" and the skills of the project leader are stressed.

122. Vlachy, Jan, "The measures of interdisciplinarity in research." Czechoslovak Academy of Sciences (June 1971).

Features a 92-item bibliography, including much Eastern European literature; grapples with the question "what is interdisciplinary research?".

123. Vlachy, Jan, "More data on interdisciplinarity." Teorie a Metoda 3 (1971): 63-79.

Presents a quantitative picture of interdisciplinary and multidisciplinary activities. A range of bibliometric data is displayed by specialty and author.

124. Walsh, W. B., G. L. Smith, and M. London, "Developing an interface between engineering and the social sciences." American Psychologist 30 (1975): 1067-1071.

Describes a first-hand experience with teaching an interdisciplinary course in societal problem-solving and the virtues of a student-centered approach.

125. Walters, C., "Interdisciplinary approach to development of watershed simulation models." Journal of the Fisheries Research Board of Canada 32 (1975): 177-195.

The key feature of the approach is "intimate involvement of resource specialists in the model building process, so that communication between resource disciplines is greatly enhanced." Two watershed models are discussed at length.

126. Weinberg, A. M., "Scientific teams and scientific laboratories." Daedalus 10 (January 1970): 1056-1075.

The author seeks "to trace the origins of big team science..., to estimate the capacity of this new scientific style to launch and carry off the scientific breakthroughs so necessary for the progress of science, and finally to speculate on the future of team research and its institutions." The author urges "trying an interdisciplinary team attack."

127. Weingart, Jerome M., "Transdisciplinary science - Some recent experience with solar energy conversion research." Annual Meeting, American Association for the Advancement of Science, Denver (February 1977).

An informal think-piece informed by the author's experiences at the Caltech Environmental Quality Laboratory in a solar energy research team.

128. White, I. L., "Interdisciplinarity." In S. R. Arnstein and A. N. Christakis (eds.), Perspectives on Technology Assessment. Jerusalem: Science and Technology Publishers, 1975: 87-96.

A review of the author's experiences in the University of Oklahoma Science and Public Policy Program. Four salient items in the conduct of interdisciplinary technology assessments are discussed: language problems, quality control, institutional barriers/incentives, and personality characteristics associated with team success.

129. Wilbanks, Tom, "Communications between hard and soft sciences." Oak Ridge National Laboratory Review, (Spring 1979): 24-29.

Reflecting on his experiences in "an interdisciplinary technology assessment program" at the University of Oklahoma and as a senior planner at ORNL, the author describes ways to "build a first-rate social science research capability in a research institution that has always emphasized the physical sciences, life sciences, and engineering specialties." Wilbanks' prescription includes "joint responsibility for written reports," physical proximity of team members, and the presence of "exceptional gatekeepers."

130. Wilcox, Timothy J., "The Interpersonal Group As a Facilitative Structure for Grant Review Decision-Making." PhD Dissertation, University of Nebraska, Lincoln, 1982.

Notes that there is evidence that grant support depends on acceptance by most dominant members of the grant review group. Suggests possible utility of the "Interpersonal Transaction" approach wherein all interaction except voting on the proposal's merits takes place in dyads (every combination). Experiment with psychology undergraduates supports possible efficiacy of IT in mock proposal review process.

131. Williams, Anne S., Nielsen, G. A., Shovic, H. F., Stuart, D. G., and J. W. Reuss. Guidelines for Conducting Interdisciplinary Applied Research in a University Setting. Montana State University, Institute of Applied Research Monograph No. 2, Bozeman, MT, (April 1976, available through NTIS PB 260 503), 22 pgs.

Researchers reflect on the experiences of a six-year sequence of interdisciplinary research projects on the proposed Big Sky resort development in Montana. This large scale, university-based effort began with 27 subprojects, experienced a shift in project goals as the sponsoring NSF unit changed from IRRPOS to RANN, and readjusted its research management strategy markedly. This report chronicles

project activities in terms of interdisciplinary research issues.

132. Winnicki, T. and B. Glowiak, "Management of large-scale interdisciplinary environmental programs." R&D Management 8 (1978): 127-132.

Summarizes the experience of organizing and managing environmental research programs in Warsaw.

133. Wohl, R. Richard, "Some observations on the social organization of interdisciplinary social science research." Social Forces 33 (1955): 374-383.

The author observes, in 1955, that "interdisciplinary ventures abound" in the social sciences; that a 1952 survey at Harvard reveals that "the chief complaints against interdisciplinary research seemed less directed to its intrinsic characteristics than to the uncritical enthusiasm of some of its advocates"; and that "the occasion for interdisciplinary collaboration arises from the very fact of specialization." Finally, "the successful conduct of an interdisciplinary research enterprise imposes on its members and leadership the need to synchronize moods, feelings, and social relationship as well as their pattern of ideas and inquiry." Sobering words to read in 1982: how far has interdisciplinarity come? Wohl anticipates that, too: "Interdisciplinary social science research is essentially an act of faith continually renewed by the hopeful."

134. Wolfle, Dael L., "Interdisciplinary research as a form of research." Journal of the Society of Research Administrators 13 (Fall 1981): 5-7.

Lead article in a special issue devoted to interdisciplinary research. The author reminds us that consensus on the definition of interdisciplinary research is lacking, and that both management issues (related to people) and scientific issues (related to work) are involved in such research and must be analyzed accordingly.